A TREATISE ON CERAMIC INDUSTRIES

A TREATISE ON CERAMIC INDUSTRIES

A COMPLETE MANUAL FOR POTTERY, TILE, AND BRICK MANUFACTURERS

BY

EMILE BOURRY

A REVISED TRANSLATION FROM THE FRENCH
WITH SOME ADDITIONAL INFORMATION

BY

ALFRED B. SEARLE

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TRANSLATOR'S AND REVISER'S PREFACE.

The lack of technical ceramic treatises of a general character in the English language has long been a serious drawback to the progress alike of the student and the manufacturer, and in view of this fact, and also that during the last few years an increasing interest has been manifested in systematic ceramics, it has been felt that the re-issue of such a work as this might prove opportune.

M. Bourry's work has long been recognized as a standard work by the practical potter, who finds that the reports of researches demand more time for study than he can devote to such matters, whilst other works lack the good classification and concise method of statement which is one of the happiest features of M. Bourry's book. Unlike many other works, it also treats of the manipulation of every class of ceramic ware from the common brick to the finest porcelain, and thus enables the reader to compare the effect of the general principles governing the manufacture of the most diverse products.

As the book is intended for practical men rather than for the scientist, no attempt has been made in translating to revise the chemical nomenclature except where the subject seemed to be of special interest, and in many cases the popular names of chemicals have been retained.

Obsolete theories have in some instances been omitted, and the general descriptions have been shortened as much as was thought to be possible without sacrificing clearness of expression or omitting important facts. At the same time, no attempt has been made to materially alter M. Bourry's original work. For this reason some of the statements made must be accepted on their own merits and not as necessarily representing the reviser's opinions; special notes have been included where they appeared to be desirable. For the same reason, many illustrations in the original have been retained, though they represent French and not English machinery. In a few cases, illustrations of modern English machinery have been substituted.

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Failing to recognize that there is much which is technically common to all ceramic manufacture, some British potters still imagine that their experience is unique, and, therefore, to be kept absolutely secret. This is unfortunate, but the present willingness of numerous manufacturers to combine in pursuing such technical research as relates to subjects and methods common alike to all their manufactures, is a step forward in the right direction, though it can never replace the necessity for highly specialized study, the results of which must, under present commercial conditions, often remain unpublished.

It is still unfortunate that there is no work written by a qualified English writer and dealing with the whole subject of ceramics somewhat on the lines of the present book, but giving in greater detail the various methods of working in this country, though its usefulness to the industry as a whole must be apparent. A number of such works are available to French and German potters, but, hitherto, the demand for such a book has not been thought to be sufficient to justify its publication. Meanwhile, the reception accorded to the previous English editions of the present work encourages the publishers to re-issue it in its present revised form.

ALFRED B. SEARLE.

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CHAPTER I.

DEFINITION AND CLASSIFICATION OF CERAMIC WARE.

Definition.—In nature is a great number of rocks or earths which —either in their natural state or after crushing or grinding—when mixed with water, form plastic pastes which can be easily moulded into shape and can retain the shape so given to them. These pastes, when dried and afterwards heated to a sufficiently high temperature, lose their plasticity and become hard bodies, the shape of which cannot be altered by small pressures. These minerals are designated under the general name of *clays*, though this "definition" must not be applied too rigidly, as many substances which are not clays are included in it.

Clays, whether pure or mixed with other substances, on suitable treatment, including the addition of water, form what is known as *plastic bodies*. This is the principal characteristic of clays, and on it almost all the ceramic industries depend. Articles made from such plastic materials are termed "green ware" when first they receive the form of the piece to be manufactured, and "biscuit" after they have been subjected to the process of firing. The word *body* in ceramics signifies both the plastic mass of which articles are made and the substance which has become hard through firing. The mass can be covered, before or after firing, with a coating of "glaze," which vitrifies under the influence of heat, and serves either to decorate the article or to render it impermeable to most liquids.

All the various kinds of articles obtained by these processes—bricks, tiles, pipes, terra-cotta, earthenware, stoneware, china and porcelain—are included under the general name of *pottery* or *ceramic ware*. They can consist of (1) a body alone, or (2) a body and a glaze, or (3) a body covered with a second body and the whole covered with a glaze. Such ware may also be decorated by painting, spraying, printing, moulding, modelling and in other ways.

Ceramic products supply the most diverse needs of man and enter as important factors into the construction and decoration of buildings; they supply the most varied domestic requirements and are indispensable for building furnaces of all kinds, for the manufacture of chemical products, they render important services to agriculture and sanitation, in the drainage of water and sewage; horticulture makes considerable use of them, and, finally, they lend themselves to the creation of decorative pieces, uniting the art of sculpture to that of the painter. Thus, clay products are an essential element to civilization, of the same value as wood or metal, and more important than glass or natural stones.

This variety of application entails diversity in the methods employed in the manufacture—from the humble workshop of the primitive potter, to the modern factory with its large machines and complex appliances, employing all the resources of industry and science. Again, the potter's aim is at one time to produce a cheap piece of ware, at another time he endeavours to produce works of art in which the price of the raw material is not one-thousandth part of the value of the finished article.

Notwithstanding their great variety, the ceramic products form a very distinct group, and differ from most other productions of industry and art, because their manufacture is almost always based upon the chief property of clay—the capability of forming with water a plastic body which becomes hard under the influence of heat. In this way, ceramic products are quite distinct from those of *glass*, in which the plasticity necessary for shaping is obtained when the mass is in a state of pasty fusion, and not in a cold plastic body. They are also distinguished from articles made with cements and other analogous agglomerated wares which harden by the "setting" of the binding agent, and not by the action of heat.

There are, however, two exceptions to this general characteristic which are included in the term pottery :—

(1) Certain porcelain wares, the body of which does not include clay, but is properly termed "glass," and

(2) Certain refractory wares in which clay is replaced by other materials, such as lime, which form a cement or binding agent by combining with one of the constituents of the body. Thus, in making silica bricks, lime is added and combines with some of the silica to form a calcium silicate which acts as a cement which really forms part of the mass.

These wares are, however, classed as pottery, because they are produced by the processes usually employed in its manufacture.

General Principles of Classification.—The variety of ceramic products demands a method of classification which will group together all those which have similar properties and will separate them from others. This is peculiarly difficult because in all the methods of classification hitherto proposed, there is too much overlapping and it is impossible to distinguish clearly the points of transition. Thus, to anyone with a sufficient knowledge of ceramics, *terra-cotta* and *stoneware* are quite distinct both in their properties and their value and it is important to differentiate them clearly. One of the chief characteristics of stoneware is its impermeability, which is due to the fact that it contains sufficient vitrified or glassy matter to fill all the interstices or pores between the other particles. Terra-cotta, on the contrary, has a porous body. If the distribution of the temperature in the kiln is irregular, some of the ware will be impervious and rightly termed "stoneware," whilst other ware, in the same kiln, will have a porosity between that of terra-cotta and stoneware. Indeed, judged by their porosity alone, portions of some articles may be porous whilst other portions may

be impervious, so that on such a basis of classification, an article might be defined as " stoneware " if viewed from one side and as " terra-cotta " if viewed from another !

Another difficulty of classification exists in the relative value of the distinctive properties of the ware, a value which is not the same for different trades. Thus, the chemical composition of the body is of minor importance in ordinary bricks, but it is of predominating importance in firebricks. It also matters little, for many purposes, whether a piece of stoneware has a coating of glaze or not, whereas a piece of pottery which, while unglazed, is of little use or value, may be converted into a valuable piece of *fine earthenware* if it is suitably glazed.

No general classification can be based on one determinate property without taking others into consideration, but should be confined as far as may be to grouping the principal kinds of pottery which, by the similarity of their properties, have most in common with each other.

The most distinctive characteristics which serve to differentiate pottery wares can be divided into four classes :—

(1) Obvious differences in the physical properties, e.g. whether a body is vitreous or porous, impermeable or permeable, transparent or opaque, hard or soft, white or coloured, fine- or coarse-grained, matt or glazed, or whether the glaze is hard or soft, transparent or opaque, etc.

(2) Differences in the shape and uses of the articles.

(3) Differences in the chemical composition of the body and of the glaze.

(4) Differences in the processes of manufacture.

The differences in the first group have the advantage of being easily and rapidly observed, and also enable the ceramist to judge, to some extent, the chemical composition and the mode of manufacture, so that they form the foundation of all classifications of pottery. The other differences are chiefly used for sub-classifications.

The establishment of a classification based solely on chemical composition, shape or use is unsatisfactory because it does not take into account other physical properties, or the influence of firing on the ware.

Among the ancients, and up to the middle of the eighteenth century, there was no classification, but only a naming of pottery ware. This method was sufficient so long as the ceramic industries remained strictly localized, but resulted in an inextricable confusion when attempts made to imitate Chinese porcelain caused a stir in Europe and produced new kinds of pottery. Thus, the most authentic writers of the seventeenth and eighteenth centuries constantly confuse the terms *faience* and *porcelain* because of the custom of calling all kinds of ware by the name of the pottery momentarily popular. At this period, also, the expressions such as *opaque porcelain* and *ironstone ware* appear as substitutes for the term

"earthenware," which had then fallen into discredit, but again became fashionable in the nineteenth century.

Brongniart in his masterly "Treatise on the Ceramic Art" gave, in 1844, the first rational classification, and this has been widely adopted as far as its principal divisions are concerned. Brongniart divided all pottery into two classes: that which has a soft body, and that which has a hard body, i.e. according as the body is or is not capable of being scratched by iron; the second group is subdivided into two classes, according as the body is opaque or transparent. By this means three large classes are obtained:—

(1) Pottery ware with a soft body.
(2) Pottery ware with a hard, opaque body.
(3) Pottery ware with a hard, transparent body.

These three divisions were subdivided, by Brongniart, into nine orders, according to the chemical composition of the glaze, as shown in the following table:—

Classes.	Names and Characteristics.	Orders.	Names and Characteristics.
1st Class.	Pottery with a soft body which can be scratched by iron: chiefly sandy-clayey, calcareous bodies (generally fusible at or below 1400° C.).	1st Order.	Terra-cotta and other articles with a sandy-clayey body, matt surface, without any glaze. Subdivisions:— (*a*) Plastic ware (moulded). (*b*) Coarse pottery ware, tiles, bricks, crucibles (moulded). (*c*) Matt ware, jars, vases.
		2nd Order.	Lustre-ware: slightly glazed with a silico-alkaline glaze.
		3rd Order.	Glazed-ware with a lead glaze.
		4th Order.	Glazed or enamelled pottery, common earthenware with a stanniferous glaze and roof-tiles, floor-tiles, bricks, etc., with a vitreous glaze.
2nd Class.	Pottery with a hard, opaque body which cannot be scratched by steel, the body being siliceous or clayey and almost infusible.	5th Order.	Fine earthenware with a white or colourless body and a vitro-plumbiferous glaze.
		6th Order.	Stoneware with a coloured body, without glaze or with a silico-alkaline glaze.
		7th Order.	Hard porcelain, the body being chiefly composed of kaolin and the glaze of felspar.
3rd Class.	Pottery with a hard translucent body, composed of clay, silica and fluxes; it is more or less fusible.	8th Order.	Natural soft porcelain with a clayey, phosphatic, kaolinitic body and a vitro-plumbiferous glaze.
		9th Order.	Artificial soft porcelain with a glassy or saline body and a fritted vitro-plumbiferous glaze.

The chief objection to this classification is in the division of earthenware into two distinct classes—of hard and soft bodies—in the first of which is included enamelled pottery or " common faience " and tin-enamelled earthenware, and in the second, fine pottery, pipe-clay ware and flint ware, for the value or distinction of a piece of pottery does not depend solely on the hardness and whiteness of the body, and these are no longer regarded as such distinguishing characteristics as when Brongniart made his classification.

Among manufacturers of decorated earthenware, the glazing is regarded as of first importance ; the body is only a support, and its defects are concealed, if necessary, by the use of a slip or an opaque enamel. Hence, this kind of pottery has not the commercial importance which Brongniart assigns to it. The position of some bodies which cannot be scratched by iron, e.g. certain vitrified bricks and floor tiles, is also anomalous.

Salvetat proposed, about 1857, to base a classification on (*a*) simple pottery (without glaze), and (*b*) compound pottery (ware composed of body and glaze), and to subdivide these classes into (1) opaque and (2) transparent wares, further subdivisions taking into account the composition of the body and that of the glaze. This classification is very extensive and dogmatic, but is impracticable, unnatural, and impossible to justify.

In Germany, Knapp's classification has been widely adopted ; it may be summarized as follows :—

I. *Impermeable Pottery.*	II. *Porous Pottery.*
A. Porcelain :—	A. Earthenware :—
(1) With glaze.	(1) Fine, with transparent glaze.
(2) Without glaze.	(2) Common, with opaque glaze.
B. Stoneware :—	B. Coarse pottery.
(1) With glaze.	C. Bricks, tiles, refractory wares, etc.
(2) Without glaze.	

In this classification the importance of the glazes is exaggerated. Moreover, a piece of " fine " earthenware need not have a transparent glaze, nor need common earthenware have an opaque glaze.

Kolbe based his classification on the raw materials used for the body, then on the examination on the surface of the pottery, and divided ware into (i) clayey pottery, and (ii) kaolinic (or porcelainic) pottery. This classification is not very practical, as it is not of necessity revealed by the physical properties of the body, nor by its chemical composition, and a body which contains both ball clay and kaolin would not find a place. There is also a possibility of confusion in the meaning attached to the words " soft " and " hard," which, for clayey pottery denote the physical hardness of the body, and for kaolinic pottery its resistance to the action of heat.

Bruno Kerl adopted a classification which is derived from those of Brongniart and Knapp :—

I. *Porous Pottery.*	II. *Impermeable Pottery.*
1. Bricks, tiles, terra-cotta.	1. Stoneware :—
2. Refractory ware.	(*a*) Ordinary.
3. Artistic pottery.	(*b*) Fine.
4. Common pottery.	2. Porcelain :—
5. Ordinary earthenware.	(*a*) Hard.
6. Fine earthenware.	(*b*) Naturally soft.
7. Pipes.	(*c*) Artificially soft.

This classification is excellent, though it makes a distinction between artistic and common pottery, which is very difficult to determine, and creates an exclusive class for " pipes " without assigning any place to " parian ware."

Bourry's Classification.—The author prefers to make the first division of his classification separate pottery into permeable and impermeable wares ; this distinction is only applicable to the body and not to the glaze, which is always impermeable. Permeable pottery, when immersed in water, absorbs some of it, but impermeable pottery absorbs very little or none, so that the permeability can be measured by immersing the body in water, and noting the weight of water absorbed at the end of a given time. The details of this test, as well as the limits within which the permeability can vary, are dealt with later.

Permeable pottery, showing an earthy fracture which is rough to the tongue, is generally soft, and can usually be scratched by steel.

In permeable pottery, pure clay, rendered more or less fusible by fluxes, plays the part of an agglomerant ; impermeable ware may be regarded as a kind of glass which is capable of assimilating in its mass a large proportion of non-vitrified material. All impermeable pottery is permeable before the completion of the firing. Alternatively, permeable or porous ware may be regarded as consisting of inert particles which are united solely at their points of contact, whilst impermeable ware is regarded a composed of similar inert particles all the interstices between them being filled with glassy matter which, on cooling, forms a solid mass ; it only becomes impermeable at a temperature which causes the glass-forming material to soften and vitrify. If, on the other hand, most of what is commonly termed permeable or porous pottery is heated to a temperature at which it becomes impermeable, it loses its shape and is transformed into a vitreous slag.

E. Bourry subdivides ceramic wares into five sub-groups, viz :—

(*a*) *Permeable Ware.*
(i) Terra-cotta.
(ii) Refractory wares.
(iii) Earthenware.

(*b*) *Impermeable Ware.*
(iv) Stoneware.
(v) Porcelain.

The term *terra-cotta* comprises all permeable ceramic wares which are not covered with glaze and whose body cannot be heated to a temperature higher than that used in firing hard porcelain (1375° C.) without losing its form or becoming vitrified. Terra-cotta is usually rather soft, but some cannot be scratched by iron, and some is scarcely scratched by steel. The colour varies from light yellow to red and reddish-brown, but is occasionally grey or black, and may be white.

Refractory Wares are distinguished in that they can be raised to the temperature at which hard porcelain is fired without losing their shape or beginning to vitrify.[1] They can always be scratched by steel and usually by iron. Their colour varies from dirty white to yellow or light grey ; in exceptional cases they are black.

The term *earthenware* comprises all permeable pottery with a coating of glaze. The body may be either soft or hard, white or coloured.

Stoneware is pottery with a coloured, opaque, impermeable body, although sometimes the colour is only slight. The surface may be matt or covered with a glaze.

Porcelain (including *chinaware*) is pottery with a translucent white, impermeable body, the surface of which may be matt or covered with glaze. The body is sometimes coloured artificially for decorative purposes.

The distinction between stoneware and porcelain lies in the translucency of the body, and is a fairly clear one ; the possibility of confusion only arises in the cases of certain bodies, which, when almost vitrified, resemble stoneware, and of some kinds of earthenware with a hard slightly translucent body, which could be grouped with porcelain of poor quality.

The following table shows the relationship between Bourry's and Brongniart's classifications :—

Bourry.	Brongniart.
I. Terra-cotta	1. Terra-cotta.
	2. Lustre pottery.
II. Refractory ware.	
III. Earthenware	3. Glazed pottery.
	4. Enamelled pottery.
	5. Fine earthenware.
IV. Stoneware	6. Stoneware.
V. Porcelain, including china-ware	7. Hard porcelain.
	8. Natural porcelain.
	9. Artificial porcelain.

[1] It is now usual to exclude from the term " refractory " all ceramic materials or articles which show any sign of fusion when heated to 1550° C.

CHAPTER II.

BRIEF HISTORY OF CERAMICS.

Ancient Ware.—By making use of the fairly plastic deposits of the River Nile, the Egyptians in very ancient times manufactured bricks of rough earth, which, in the earliest days, were merely dried by exposure to sunlight, but in later, though still ancient times, were fired in a primitive type of kiln. In some excavations made by Linant Bey, fired bricks were found at a depth of twenty-five to thirty feet below the level of the valley of the Nile, and this depth, with the progressive elevation of the soil, suggests that the beds containing those bricks were deposited 10,000 years or more ago. According to Mariette Bey, vases of terra-cotta which were intended to contain provisions for the deceased have been found in the tombs of the Memphite period (5000-3000 B.C.). On the walls of other tombs, pictures have been discovered portraying scenes from the life of Egyptian potters, modelling vases and firing them in an oven, at a time corresponding to the Theban period (3000-1700 B.C.) ; to this period is also attributed the discovery of glazes and the manufacture of some of the earliest pieces of earthenware, viz. those found in the pyramid of Saggarah. Between 1700 B.C. and 500 B.C. the art of earthenware-manufacture acquired a rare perfection, as shown by the decorations of the temple of Tell-el-Yadouai built by Rameses III.

Whether the Chaldeans and Assyrians borrowed their processes from the Egyptians, or whether they discovered these processes for themselves, is not certain, but it is known that after having for a long time used crude bricks in their buildings they erected the palaces of Crœsus at Sardis, of Mausolus at Halicarnassus, and of Attalus at Tralles in beautiful, red, fired bricks. The ruins of Nineveh and Babylon consist of accumulations of fired bricks of a yellowish-white colour, sometimes covered with blue, bluish-grey or yellowish-white glazes. Tombs made of a single piece of ware, or formed by two pieces cemented together, evince the skill of the Chaldean and Assyrian potters at this remote period.

It is possible that the Indian races learnt the manufacture of fired bodies and glazes from the Assyrians and Chaldeans ; in the Vedic hymns mention is made of pottery.

The Persians, who succeeded the Assyrians, carried the manufacture of monumental ware to a high degree of perfection. The body employed by the ancient Persians was extremely silicious,

having the appearance of a piece of soft stone. It appears to consist of sand containing only a little clay, and its very low plasticity rendered it very difficult to shape it by moulding. The ornamentation in low relief was probably carved by hand, on either the green or fired body. The glazes used are very alkaline, possessing much brilliancy when white, as well as with yellow or blue colours. At a later period, the Persians used more plastic bodies for making vases, dishes, etc.

It is curious that Greeks and Romans, whose intercourse with the Persians was so frequent, never borrowed the magnificent art of enamelling from them. Possibly the Greek desire for purity and delicacy of form caused them to dislike an enamel which would clothe an object with any pasty material, but this could scarcely apply to the Romans, who were very prone to adopt the usages of the nations they conquered.

The art of *faience* was introduced into Europe from Persia by the Arabs and Moors after it had been ignored by all the classic nations. Towards the eleventh century, when the Arabs were superseded by the Moors, a new kind of ware appeared in Spain, which was distinguished from the Persian wares chiefly by the metallic lustre of the glaze. The manufacture of the celebrated Hispano-Moresque faience, wall tilings, dishes and vases, many of which showed great purity of form, became concentrated in the Island of Majorca, at Malaga, and at Manises, near Valencia. The celebrated vases which adorn the Alhambra at Granada, and are considered to be masterpieces of Moorish ceramic art, were probably manufactured at Malaga about 1320. The conquest of Spain by the Christians struck a fatal blow to this fine industry, and after declining rapidly it disappeared entirely from the localities it had rendered famous, leaving the honour of inheriting this glorious art to Italy.

The Phœnicians and Greeks, neglecting glazes, manufactured terra-cottas of such an artistic character that they caused the spread of the ceramic arts among all the nations bordering on the Mediterranean and in the north of Europe. The Greeks are important because of the perfection of the form of their pottery, and the Romans because they were the first to apply ceramic products for the purposes of construction, and because Southern Italy was the country from which originated "Campanian" ware, which will long remain the most perfect model of pottery in fired body. In addition to the admirable purity of form, the Greek potters used fairly fine clays, probably washed and fired at a rather high temperature, which gave the ware a special hardness and fineness. They either polished the surfaces before firing, in order to give a kind of "finish" to the fired pottery, or used the process of decoration known as "slipping," which consists in ornamenting the body by applying to it another body of a different colour though the manner in which such Samian ware was glazed is still unknown. Later, they discovered how to produce a lustre glaze which, by its strongly

alkaline composition, brought about the vitrification of the surface, These wares were coloured red by oxide of iron, or dark brown by a mixture of the oxides of iron and manganese.

The aborigines of Mexico and Central America made some remarkable terra-cotta, the origin of which dates, probably, from before 1000 B.C. The manufacture of terra-cotta was thus invented by three different peoples—the Egyptians, the Chinese, and the Mexicans (Aztecs)—at periods too remote for accurate dates to be assigned to them.

According to the Chinese, the first pieces of pottery in China were manufactured by Kouen-Ou, during the reign of the Emperor Hoang-Ti (2698-2599 B.C.), but their great discovery, that of impermeable pottery (stoneware and porcelain), is much more recent; the first mention of it being made in a work published in the reign of the Emperor Wan-Ti (175-151 B.C.).

About the eleventh century the potteries of Italy became the most renowned in Europe. The intercourse between Italians and the East gave them a knowledge of Arabian faience and metallic lustres, which they strove to equal. For many centuries they were content to be imitators, but in 1440, Luca della Robbia, a native of Florence, made use of stanniferous, opaque enamels for the production of a new kind of ware, which for three centuries held the chief place in ceramic art. Della Robbia was a sculptor, and his object in covering fired bodies with enamel was to render them imperishable. His principal works are statues, or groups, covered with enamel of a uniform colour, chiefly white and blue, sometimes green, rarely brown or yellow. The great discretion used in his colours and the purity of style shown in his shapes, marks his work with a peculiar characteristic of serenity which is not found among that of many of his successors. At his death, Luca was succeeded by his nephew, Andrea, who had seven sons, five of whom became distinguished ceramists; they produced bas-reliefs, friezes, statues, medallions, and altar-pieces remarkable for the perfection of the technical processes displayed. "The enamel on them," says M. Garnier, "is very smooth and without any cracks; the clay is well fired, and the shrinkage has been so cleverly calculated that the parts which compose the bas-reliefs and statues of large dimensions are adjusted and placed together without leaving any gap."

Up to the fifteenth century, the only glaze known was of a plumbiferous nature. Its transparency allowed the yellowish or red colouring of the body to be seen. The origin of its use is unknown, but it is generally admitted that it was known to the Egyptians, Greeks and Romans and, though little used by them, was handed down until, in the thirteenth century, it became more largely employed.

At the end of the fifteenth century the manufacture of a new stanniferous faience developed considerably throughout the whole of Italy. This was known by the name of *majolica*, a corruption of the name of the island of Majorca. This designation has been

the cause of much discussion as to whether the Italians received their inspiration from the Moors of Spain or the Arabs of the East. It seems probable that they came under the influence of both.

At Faenza in the Marches, which has given its name to the French word "faience," since 1487, wall tiles were manufactured; later this town became known for its blue decorations on a blue enamel of another shade (*berettino*), and the presence of red tints in the painting.

At Urbino lived many ceramists whose names are worthy to be preserved, including Guido Durantino and Francesco da Rovigo (before 1545), Orazio Fontana (at the end of the sixteenth century), and Antonio Patanazzai (at the beginning of the seventeenth). At Urbino also reproductions of the pictures of Italian masters, and particularly of Raphael, were first made. Here also were manufactured grotesque pieces, ornaments in relief, salt-cellars, inkstands and vases fashioned by Battista Franco, and executed by Orazio Fontana, which are considered to be the masterpieces of the Urbino factory. The most illustrious artist of Pesaro was Gironimo Vasaro, who was famous for vessels and metallic lustres, but the manufacture ceased there at the beginning of the sixteenth century. Of all the potteries in the Duchy of Urbino, that of Castel-Durante was the most active, if not the most artistic, but it was closed at the beginning of the eighteenth century. Its faience was distinguished by the size and boldness of its designs, and by the brownish colour of the decoration which was generally on a blue or yellow ground.

Italian ceramists raised themselves to the highest degree of their art, and evinced a professional skill of a high kind in extracting the fullest worth from the materials they employed, but their work—after having reached its culminating point in the middle of the sixteenth century—declined rapidly, and disappeared almost entirely at the beginning of the seventeenth century.

French Faience.—The use of lead glazes on a porous body seems to have spread in France during the twelfth century. They were used first of all to cover bricks and paving tiles and later in the manufacture of vases and other vessels of various shapes. From 1225 a factory for this kind of pottery existed at Troyes, another at Pontaillier, near Dijon, and others later at Paris and Saintes, but lead glazes were most used at Beauvais, and in the neighbouring localities of Savignies and La Chapelle-aux-Pots. From the sixteenth century, however, this kind of glazed pottery lost its artistic nature, and was only employed for domestic ware; for this purpose it has continued till our own day, though on the continent of Europe generally it tends to be replaced by ware with an impermeable body.

The first pieces of faience of purely French origin are those named after Oiron, and were remarkable for the white ivory tint of their very hard body and the lightness and finish of their decoration; their forms resembled those of goldsmith's work. This

remarkable manufacture died out completely without exercising any influence on the development of French ceramics.

Bernard Palissy settled about 1542 at Saintes (Charante-Inférieure), and there discovered the composition of a white enamel or, more probably, learned to make such an enamel of Italian origin, patterns of which had come into his possession some years previously. By means of experiments, which were frequently impeded by poverty, he succeeded in producing faience of an original character, which attracted the attention of many great nobles, and particularly that of the High Constable de Montmorency. After many years devoted to ceramic work, he established himself, in 1562, at La Rochelle, and afterwards at Paris, where he enjoyed the protection of Catherine De Medici, but after the death of his protectress was imprisoned and died at the age of 80.

According to Blondel, Palissy produced wall-tiles, stove-tiles, vases decorated in various styles, ewers, cups, salt-cellars, ink-pots, candlesticks, and even statuettes ; but his most remarkable works are his " rustic dishes " with ornamentations of fishes, serpents, frogs, crayfish, lizards, shells and plants. They were not made for use, but as show pieces for the sideboards, and were at one time greatly in fashion. Palissy insisted on keeping to himself the secret of his remarkable works : " thus the art which he had so painfully learnt disappeared almost entirely with him, his immediate successors producing only works of mediocrity, relatively dull, without any ingenuity, and made from old moulds."

It was not till 1602 that the Conrade Brothers began to manufacture faience at Nevers, following the process which they had learnt in Italy. The family died out in 1677, but other factories were established at Nevers, the most important being directed by the Custade family. " The productions of this period," says M. Garnier, " are remarkable for their free and ingenious execution and especially for the beautiful blue often accompanied by manganese."

In 1673 the first manufactory of faience was established at Rouen by Louis Poterat, who created the Rouen style, which takes first rank among French faience, and by many is preferred to the most beautiful productions from the Urbino works. " These are designs, without relief, forming cartouches and scallops, which, being distributed symmetrically over the surface of the pieces, radiate round the centre if it is a dish or plate, but, in the case of vases, descend from the edge and spread over the centre. This kind of decoration is usually in blue on enamel white, but yellow, green and red are met with on these pieces " (Darcel).

The Moustiers faience factory was founded about 1680 in a small town in the Basses-Alpes, by the family of Clérissy, who produced an original type of decoration, and founded a school whose influence was felt in every factory from the South of France to Spain.

The Hannong family, who were very eminent ceramists, founded at Strasburg, in 1709, a factory which remained till about 1790.

Contrary to preceding manufacturers, the Hannongs, following the processes used for porcelain, painted their decorations on the fired enamel and not on the green material. M. Garnier says: "The faience wares of Strasburg are distinguished by the beauty and purity of their enamel, by their elegant and fantastic forms, and especially by the vivacity and freedom of their colours—notably purple and carmine."

To these four great centres of French faience ware—Nevers, Rouen, Moustiers and Strasburg—each of which had its peculiar characteristic, should be added a great number of other manufactories which are more or less connected with them, including—to cite only the best known—Marseilles, Montpellier, Bordeaux, Lunéville, Niderviller, St.-Amand, Sceaux, Lille, and Epinal.

The manufacture of stanniferous enamelled faience, which had attained so much splendour for so long a time, began to decline in the eighteenth century. The older works were closed and the newer ones were unable to compete with porcelain and porcelain-imitations which emanated either from the factories then recently established in Paris and in many places, or were imported into France through the agency of the East India Company. In addition, a new kind of pottery which at that time began to be made in England accounted, in a great measure, for the decline of stanniferous ware.

German, Dutch and Other Faience.—Pottery covered with lead enamels developed largely in Germany during the close of the Middle Ages, being used for architectural pieces as well as for vases, etc.

Nuremburg was already celebrated for its pottery ware when, in 1503, Hirschvogel, who was sent on a mission to Italy, there learnt the secrets of the manufacture of majolica. In the eighteenth century Nuremburg also became famous for dinner ware and for show-pieces (usually decorated with loose bouquets) but the finest stoves used for domestic heating in Germany and for which Nuremburg was, at one time, celebrated, date from the sixteenth century, and by the eighteenth century this manufacture had fallen into decay.

Among other German faience factories are those at Ansbach (Bavaria), where fairly good imitations of the Rouen ware were made; Höchst-on-Main (1720-49) where a decoration was used which resembled that on porcelain; Frankenthal where the wares of Strasburg were imitated, and Bayreuth where services and vases were made—generally with blue decorations.

Towards 1584 there was founded in the Netherlands an earthenware manufactory, which by the end of the seventeenth century became of considerable importance, both for its output and the artistic value of the ware. Under the strict supervision of the Guild of St. Luke, the Delft productions rendered the name of that town famous, yet the earlier factories experienced the same fate as the French ones and disappeared about 1800. Among the numerous

ceramists who contributed to the fame of Delft were Herman, Adrian and Gerrit Pietersz, Albrecht de Keyzer, Abraham de Kooge, Frederick van Fryton, van Eenhoorn and Augustijn Reygens.

Delft ware is divided into three periods: in the first, the decoration of an ordinary character is in camaieu blue with dark portions, inclining to a violet-brown, showing great variation in compositions of the materials. The second period is characterized by a notable improvement of the same process, and by a remarkable imitation of Japanese porcelain. In the third period, which dates from the end of the seventeenth century, the object of the manufacture became principally commercial, and a multitude of articles was produced of the most varied kinds, including some remarkable imitations of porcelain ware from China, Japan and Saxony.

Amongst other places which, especially in the eighteenth century, possessed factories of stanniferous ware, were Talavera, in Spain, which gave its name to stanniferous faience in its native country; and those of less importance of Alcora and Seville. In Switzerland the factory at Zürich was celebrated chiefly for its stoves used for domestic heating, and that of Thun for its decorations by means of drops of various coloured glazes. In Sweden the Rörstrand ware imitated that of Marseilles and Strasburg in the matter of decoration and the porcelain of Saxony; that of Marienborg was influenced in its decoration by Strasburg. Factories also existed at Bruges and Liege in Belgium.

English Earthenware.—The manufacture of lead-glazed pottery and of enamelled ware has been but little developed in England. Faience was imported from Delft, which name was employed to designate all stanniferous pottery, though there existed a factory at Lambeth, on the outskirts of London, founded by the Dutch, and those at Burslem in Staffordshire. Hence when, in 1770, Astbury, the son of a Burslem potter, noted by chance the whiteness of a silicious powder used by a veterinary surgeon (since known as *china clay* or *Cornish clay*), it occurred to him to mix this powder with the faience body. The success produced realized his hopes, the body became whiter, was remarkably hard, and lent itself to all kinds of decoration. Numerous manufactories making use of this discovery were established at Burslem, Hanley, Newport, Leeds, Liverpool, Fulham and Lambeth. Of these, that of Leeds soon became celebrated, and it was not long before its productions were sent all over Europe. The ware made in these towns was, at first, of a common kind, but was brought to a high degree of perfection by Josiah Wedgwood, the most celebrated English ceramist, who was born in 1730 at Burslem, and was the son of a potter in that town. After having had several partners, he founded, in 1759, a factory, where he manufactured pottery having a cream-coloured body, which achieved a considerable success, and being patronized by Queen Charlotte, became known as *Queen's ware.* Afterwards, associating himself with Thomas Bentley, he devoted his time to the imitation of antique art, and manufactured vases, cameos,

medallions, etc., the execution of which was as remarkable as it was careful.

The wares produced by Wedgwood are classified by Professor Church as follows : (i) Cream earthenware or dinner ware, painted in colour, or printed in black or red, sometimes enriched with gold ; (ii) black pottery in the form of vases, medallions, busts, and services of various kinds, sometimes with coloured and gilt decorations ; (iii) red pottery for imitating cameos ; (iv) fine faience with a white body ; (v) a variety of stoneware imitating marble, granite, and agate ; and (vi) pieces decorated in low relief on a greyish-blue ground, in the form of vases, candlesticks, small snuff-boxes, boxes, buttons, and especially bas-relief imitations of the antique, from models by the sculptor Flaxman.

By the end of the eighteenth century the manufacture of this newer kind of faience—*fine earthenware*—in England had supplanted stanniferous faience ; at the beginning of the next century this earthenware ruled supreme, and all countries of Europe paid tribute to the fine earthenware manufacturers of Staffordshire.

Stoneware.—The history of the manufacture of stoneware is much shorter and less eventful than that of faience, earthenware, and other ware with a porous body. Stoneware was known to the Chinese many centuries before our era ; some Egyptian pottery can also be included in this category, together with a few specimens of glazed pottery manufactured during the Middle Ages, though the regular manufacture of stoneware did not begin in Europe before the fifteenth century, where it was probably first carried on at Raeren, in the Duchy of Limburg. About the same time another stoneware pottery existed at Frechen near Cologne. The wares of both factories had a yellowish body, covered with a dark brown glaze and consisted chiefly of vases and jugs with ornamentation in relief representing scenes of hunting, dancing, peasants and Biblical subjects. A stoneware pottery at Siegburg, opposite Bonn, produced matt stoneware of a slightly greyish body ; but the works at Hoehr and Grentzhausen, near Coblentz, whose wares were wrongly known as " Flemish Stoneware," had the widest reputation. The body was greyish or bluish, decorated with blue, violet or brown enamels, forming a rich ornamentation on articles of a shape which was generally elegant.

At the end of the seventeenth century, a pottery at Creussen, near Bayreuth, produced stoneware with a brown body and black glaze, chiefly used for small figures or coats-of-arms in relief, painted in light colours.

In France, the manufacture of stoneware was carried on early in the sixteenth century, at Savignies and La Chapelle-aux-Pots, near Beauvais. These wares, of a greyish or bluish body and a uniform blue glaze, enjoyed a wide reputation in the north of France until displaced by faience, after which, towards the end of the seventeenth century, the manufacture was confined to domestic ware.

About 1690, the brothers Elers, of Nuremburg, established

themselves at Bradwell in England, and there founded a pottery for stoneware with a red body, and later with a yellowish-white, with salt glaze. The reputation of their potteries soon led to rival ones being established, among which was that at Fulham, founded by John Dwight, who from 1721 manufactured jugs, dishes, goblets, etc., with a brown glaze, the ware being decorated in relief, with hunting subjects and grotesque figures.

The manufacture of stoneware made considerable progress in England, due in part to the researches of Josiah Wedgwood, and many of the Staffordshire potteries produced both earthenware and stoneware ; but a new era in the manufacture of stoneware began in 1819, when Doulton established his works at Lambeth.

Oriental Porcelain.—The earliest manufacture of Chinese porcelain ware dates back to about 200 B.C. It has a greyish body, is very slightly translucent, and the glaze is usually crazed.

Under the dynasty of Ting (A.D. 621-945) there was a considerable improvement in the manufacture, the body became whiter, the crazing disappeared, and the glaze, though generally of a greyish-green, is sometimes blue. This progress continued under the following dynasty, the body becoming fine and translucent, yellow and green colourings being added to the blue. From this period (A.D. 945 to 1368) also date the first " flambe " wares and the famous development of Nanking pottery.

Under the double dynasty of the Ming (1368-1488 and 1488-1643) Chinese pottery acquired the qualities which have rendered it famous. The style of decoration is sober, the colouring pure, and the forms were often elegant. Under the Ching-Khang-Hu (1643-1662) and the Yung-Thing dynasties (1662-1736), pink, red and violet colourings were also used.

Since the dynasty of Kieng-Long (1736) Chinese porcelain has maintained its present familiar appearance. The decoration, composed chiefly of figures, has become more and more exaggerated and the gilding, which was at first used in moderation, has ended by overrunning the whole of the decoration. Chinese pottery artists delight in the most extraordinary exhibitions of skill, but, in much modern Chinese ware, art is compelled to give place to cheap commerical productions.

In China the manufacture of porcelain has always been confined, almost exclusively, to the provinces of Kiang-Si, Canton being the place of export.

The first pieces of Chinese porcelain which came to Europe were brought by the Arabs in the twelfth century, but their place of origin was unknown until the Venetian Marco Polo's voyage to the extreme East, in 1295, and Chinese porcelain was not brought regularly to the European markets until the fourteenth century.

The Japanese annals relegate the origin of Japanese porcelain to the first century B.C., but, so far as is known, actual manufacture only began early in the seventeenth century, and it was only towards the middle of the nineteenth century that Japanese art obtained a

notable amount of independence. The body appears to be whiter and more translucent, and the decoration more careful and less heavy in style than that of most of the Chinese work.

European Porcelain.—Throughout the seventeenth century strenuous efforts were made to reproduce Chinese porcelain, but without success, because nothing was known of the raw material (kaolin) used by the Chinese, but in 1709 Böttcher, assisted by the advice of Tschirnhaus, succeeded in manufacturing what was regarded as porcelain in the Castle of Frederick Augustus II at Meissen, Saxony. Notwithstanding the extraordinary means employed at Meissen to guard the secret of the new manufacture, a foreman, Stöpzel, succeeded in escaping and founded a porcelain factory at Vienna, in Austria, and was in his turn betrayed in 1740 by a workman named Ringler, who sold the process to the celebrated manufacturer of faience of Höchst-on-Main. After many years' sojourn at Höchst, Ringler joined Hannong of Strasburg, and in 1775 founded the porcelain factory at Frankenthal; then those at Nymphenburg, near Munich (1756), and at Larisburg, near Stuttgart (1758). Ringler's recipes were stolen by several of his workpeople and sold throughout Europe at very high prices, with the result that factories were founded at Doccia, near Florence, Berlin (1750), St. Petersburg (1772), Copenhagen (1773), Rübensgrün, in Bohemia (1790), etc. The porcelain factories of Thuringia, Sitzerode, Volkstedt, Limbach, etc., the earliest of which date from 1762, were founded by the chemist Macheleidt, who appears to have independently discovered the manufacture of hard porcelain.

Many of the attempts made in Europe to manufacture porcelain proved fruitless through want of kaolin, but resulted in the manufacture of a new kind of pottery—*soft porcelain*, a material somewhat resembling glass—in 1693 by Chicaneau. Another manufactory of the same kind existed at Lille from 1708 to 1720. In 1735 factories for soft porcelain were established at Chantilly and Mennecy, near Essonne, and later, those of Sceaux, Tournay, Strasburg, St. Armand, Arras, and Vincennes were started. In 1745, the last named works was purchased by Louis XV, who transferred it to Sèvres in 1756.

Notwithstanding the considerable progress made by the manufacture of French soft porcelain, the Sèvres factory, in 1761, purchased the secret of the manufacture of hard porcelain from Hannong of Strasburg, who had recently become the proprietor of the celebrated porcelain manufactory of Frankenthal. The first trials were only made in 1765 at Bagnolet by Guettard, who had just discovered near Alençon a bed of impure kaolin, but the product was grey and of a poor quality. About the year 1765 Mme. Darnet, the wife of a surgeon at St.-Yrieix, by chance, discovered the famous kaolin beds situated near that town, and so caused the total almost abandonment of soft porcelain in France, and assured the supremacy of hard porcelain.

In England, a kind of soft porcelain was made about 1745 at

Chelsea, but the first regular manufacture of English soft porcelain, in 1751, is due to Chaffers of Liverpool, who used phosphate of lime as a flux. The discovery of the vast Cornish beds of kaolin, in 1768, improved the manufacture, which was introduced into Staffordshire in 1772, and while, in France, the discovery of kaolin had led to the abandonment of soft porcelain, the latter, in the form of *china-ware*, continues to be manufactured in England to the exclusion of hard porcelain.

Modern Ceramics.—This brief summary of ceramics brings us to the beginning of the nineteenth century, to which belonged the task of uniting the different branches of the ceramic art, of substituting for tradition and the secrets of manufacture the principles of science, of transforming the craft into an industry, and of placing the results of the privileged few at the disposal of all.

At the beginning of the nineteenth century the terra-cotta employed in building had not made any marked progress since the beginning of the fifth century, and its manufacture was carried on according to the traditions left by the Romans, who only employed it concurrently with stone, nearly always covering it with glaze, and only very rarely making use of it for decorative purposes. But from the beginning of the Renaissance the position of terra-cotta became less subordinate ; so that, whilst framework and decoration were always done in stone, in the smooth parts of the walls, bricks were left to show their natural colour.

From many large buildings in the north of France, the Netherlands, England, Germany and the United States, stone is often excluded, and terra-cotta, without any glaze, used entirely for the building and decoration, and whilst stone will remain one of the necessary elements in building, the use of ornamental terra-cotta will spread more and more.

In iron-construction, which dates from the middle of the nineteenth century, and which had its origin in France, terra-cotta is called upon to play an important part, serving the purpose of filling the metallic skeleton, and of a decorative element in the same way as faience, earthenware, stoneware, or porcelain.

The employment of mechanical presses, and of kilns fired at a more elevated temperature, have for the last forty years greatly improved the quality of solid bricks. The ornamental bricks and terra-cotta now made have a power of resistance, accuracy of form, and uniformity of colouring, which have never been excelled and seldom equalled. Hollow bricks were known long ago but were not used because of the difficulty of their manufacture, until Borie, in 1885, invented a tool which has been the starting-point of their popularity. Simultaneously, roofing tiles, in the South of France especially, have attained a hardness and beauty of appearance which they never possessed in the preceding centuries.

The manufacture of drainage pipes, which has rendered such important service to agriculture and sewerage, originated in England at the end of the eighteenth century, but it is only in the first half of the nineteenth that their use spread into Europe.

The use of terra-cotta for domestic purposes tends, on the other hand, to diminish on account of the competition created by earthenware and porcelain. In spite of the imitations, made during the nineteenth century, of the beautiful decorative pottery of the Greeks, these tend to be confined to flower vases, and to reproductions of statues, which, from an artistic point of view, leave much to be desired.

Refractory ware is an invention of the nineteenth century, during which time scientific knowledge of the properties of raw materials and the accuracy attainable in the mixings, created an industry which has rendered possible great progress in metallurgy and the manufacture of chemicals. The refractory materials industry originated in England, and spread into Belgium, France, Germany, and the United States—to mention only the chief manufacturing countries.

At the beginning of the nineteenth century the manufacture of *fine earthenware* was only carried on in England, where, following the processes originated by Wedgwood and others, a fine earthenware with a hard body, concealing itself under the names, at that time much in fashion, of "iron-stone china" and "opaque porcelain," was manufactured. The great success of this kind of pottery at the beginning of the century was the cause of the establishment of similar factories in France, Germany, Belgium, Holland, Sweden, Denmark, and more recently in Spain, Russia, Italy, and the United States, but it was not until the second half of the nineteenth century that this manufacture assumed any considerable importance on the Continent. In this connection it is interesting to contrast the fact that whilst, on the Continent, the manufacture of pottery has been chiefly concentrated in a few very large works, in England many small and medium-sized works have been built in one district in Staffordshire, which is generally known as the Potteries, in which the manufacture of fine earthenware has been an industry of considerable importance with a large and active export trade.

European factories have, by successive improvements, greatly increased the hardness and solidity of their wares, and have found, by means of clever decoration, how to conceal the excessive whiteness of some of the bodies used. More recently, several earthenware manufacturers have also undertaken the manufacture of architectural decoration, wall tiles, and sanitary ware, thus providing means for the exterior and interior furnishing of domestic and other buildings.

The manufacture of *stanniferous faience*, which was in a state of decay at the beginning of the nineteenth century, has again increased during the last eighty years. Its applications were at first confined to the manufacture of stoves; afterwards it was extended to imitations of old Moresque, Italian, French and Dutch faience, and finally to architectural decoration in combination with terra-cotta.

Deck, in the nineteenth century, revived the ancient Persian

faience, consisting of a silicious body and a transparent alkaline glaze, which owing to the brilliance and richness of its colours, is certainly among the most beautiful work which ceramic art has produced.

The manufacture of *stoneware* languished on the Continent at the end of the eighteenth century, but in England it was carried on extensively, and attained to an extraordinary degree of perfection, thanks chiefly to Doulton & Co., whose name is still connected with that kind of pottery. For the last sixty years, stoneware potteries have also increased in other parts of Europe and in the United States. At the present time artistic stoneware, manufactured principally in England, France, Japan, Germany, Belgium and the United States, enjoys an extraordinary favour.

Stoneware has still another application, less artistic, yet probably more lasting, in drain pipes and sanitary apparatus, thus making ceramics an indispensable auxiliary to the science of hygiene. Moreover, it has been widely used in the manufacture of chemical products, for which it is particularly suitable owing to its resistance to heat and acids.

Another very important branch of the stoneware industry is the manufacture of blue engineering bricks and of impervious paving tiles.

The manufacture of *hard porcelain* continued to develop during the course of the nineteenth century, the greatest centres of production being Limousin in France; Saxony and Silesia. Besides being used for table-ware and decorative pieces, it is also employed in laboratories, and, owing to its non-conductibility, for electric appliances. It has also been used for internal architectural decoration. The high temperature of the firing of its glaze, which greatly limits the number of the colours which can be used, has resulted in the search for a more fusible composition in order to facilitate decoration. Some successful attempts in this direction have been made —chiefly at the manufactories of Sèvres and Berlin.

The old *soft porcelain*, abandoned by the French at the end of the eighteenth century, is no longer made on a large scale, but *bone china-ware* or English soft porcelain continues to be largely manufactured in Staffordshire, where it is, like fine earthenware, of great importance. During the last seventy years another kind of porcelain, usually without glaze and resembling stoneware, has been made in several varieties known as *Parian* and *Carrara ware*, but its popularity is declining.

Porcelain buttons and studs and the manufacture of artificial teeth are the monoply of a few works.

In spite of the progress already made, the final stage of development of ceramics has not yet been reached. In some of its applications it seems to have arrived near perfection, but in others much still remains to be done, and the progress of metallurgy and of numerous other industries will give rise to fresh developments in ceramics. Finally, there still exist many cases in which pottery could with advantage replace the materials now employed, on account of its indestructibility or the brilliance of its decoration.

CHAPTER III.

RAW MATERIALS OF BODIES.

1. Clays.

(*a*) *Pure Clay.*

In ceramics, under the general name of "clays" are included all the rocks or natural earths which, after being mixed with water, form a plastic body, which hardens under the influence of heat (see p. 1). Clays appear to owe these properties chiefly to one or more substances, variously described as alumino-silicic acid, aluminium silicate, and hydrosilicate of alumina, which enters into their composition in varying proportions. Silica, alumina, and water form various combinations, but the one which, in the constitution of clays, plays the chief part is an alumino-silicic acid represented by the chemical formula—

$$Al_2O_3, 2SiO_2, 2H_2O,$$

and designated as *kaolinite* in mineralogy, and as *true clay* or as *clay-substance* in ceramics. Other hydrosilico-alumina compounds which can enter into the composition of clays may be considered under the same head as those other substances which, mixed with "true clay," form numerous varieties of natural clays. No entirely satisfactory definition of "true clay" exists, and the use of this phrase must be understood to refer to a hypothetical rather than to an actual substance, as the clays which correspond most closely to the formula given are deficient in plasticity, and are, therefore, deficient in the most characteristic property of clays. For many purposes, however, it is convenient to assume the existence of a hypothetical "true clay"—equivalent to a compound composed of 1 molecule of alumina, 2 of silica, and 2 of water, the corresponding percentages being 39·77 per cent alumina, 46·33 per cent silica, and 13·90 per cent water. In a moist atmosphere, true clay absorbs a certain further quantity of water, varying from 3 to 9 per cent, according to the hygrometric condition of the atmosphere and the size of the molecules.

It has not yet been possible to produce pure clay synthetically, that is to say, by the direct combination of its elements or of alumina, silica and water.

When any approximately pure clay is heated sufficiently, all

hygroscopic water or *moisture* is eliminated at a temperature slightly higher than 100° C., and a further quantity of water known as the *combined water* is first liberated at about 350° to 400° C. from the clay, its evolution continuing slowly up to about 650° to 700° C. At this last temperature the clay is completely decomposed, all its water has been eliminated, and the material remaining is composed of 46·19 per cent aluminium, and 53·81 per cent silica. It is, therefore, impossible to reconstitute the original hydrated compounds or to restore the plastic qualities of clay to this heated material.

If the temperature is raised to 700° or 800° C., the silica and alumina begin to form a new anhydrous aluminium silicate (*mullite*, Al_2O_3 SiO_2), the combination appearing to be complete between 1100° and 1200° C. Towards 1500° C. the first symptoms of vitrification appear ; on further heating to a still higher temperature, the mass grows soft, and ends by losing its shape and melting.

Any alkalies (soda and potash) in the clay attack the aluminium silicate on prolonged heating and transform it into double silicates of potash or soda and alumina.

Dilute acids have no influence on pure clay, but concentrated hydrochloric acid and sulphuric acid decompose it at a temperature of 250° to 300° C. They act in the same way, but more slowly, on the calcined clay.

The two physical properties characteristic of pure clay on which ceramic arts and industries are based are *plasticity*, which is produced on mixing clay with a suitable proportion of water, and the *hardening* which occurs under the influence of heat.

If an increasing proportion of water is added to a dry clay which has previously been crushed to a powder, a body is obtained which is more and more plastic until the quantity of water added is so large that the body becomes fluid, and its plasticity diminishes until, on the addition of sufficient water, it disappears.

For a long time, the causes of this plasticity were unknown, but the researches of Johnson and Blake, and especially those of Bidermann and Herzfeld, have confirmed the view that it must be attributed to the extreme fineness and to the laminated forms of the grains of pure clay. Certain clays having exactly the same chemical composition may yet differ considerably in plasticity. Microscopic examination has shown that these differences correspond to the variation in size of the grains, the plasticity becoming greater and greater in proportion as the volume of the grains diminishes. Moreover, this property is not peculiar to clay, for all minerals, if reduced to a sufficiently impalpable powder, on the addition of a suitable quantity of water, develop a certain amount of plasticity. This has been verified by M. Vogt as regards mica, which is made up of thin layers, very laminated, and when reduced to the form of an impalpable powder, and water is added, a body having a plasticity which can be compared with that of clay is obtained. The production of plasticity by extremely fine grinding has been attributed to the molecular attraction which can only be appreciable when the mole-

cules are extremely close together, i.e. when the particles are very minute.

The much greater plasticity of clay than other pulverulent minerals, has been attributed to pure clay being in the form of lamellar crystals entangled with one another, so that the grains are closer together than if they were polyhedral or spherical, and this is equivalent to increasing their attraction to each other in a strong degree. More recently, the plasticity of clay, mica and some other minerals has been attributed to their being in the *colloidal state* (p. 24), as most colloidal hydrogels are plastic when they contain a suitable proportion of water. Coarser particles are reduced to the state of a colloidal sol by extremely fine grinding in the presence of soda or other suitable electrolyte and some sols may be converted into plastic gels by the addition of an appropriate amount of dilute acid or other suitable electrolyte, followed by the removal of the excess of the water.

The investigation of the cause or causes of plasticity is complicated by the fact that particles of plastic clay behave as though they consisted of an inert core surrounded by a film or envelope of gel, the plasticity depending largely, though not wholly, on the film. Moreover, it has not been found possible to convert feebly plastic clays, such as kaolins and china clay into highly plastic ones, such as the ball clays, by any mechanical or chemical treatment, though a slight increase in plasticity may be effected in the manner just described. This inability to produce highly plastic clays artificially does not necessarily invalidate the theory as to their plasticity being due to their colloidal nature ; it must be remembered that the highly plastic clays have been subjected to a grinding action far more intense and for far longer periods than are available in experimental work. That this age-long grinding does not necessarily destroy the crystalline structure is shown by the investigation of W. H. Bragg and others who deduced, from the X-ray spectrum, that the particles of clay are definitely crystalline though they are too small for their shape to be seen under the most powerful microscope.

Whatever may be the true cause of the plasticity of clay it appears to be due to the physical state rather than to the chemical composition of the material.

It is interesting to consider what appears to happen when water is added to pure clay in the form of a dry powder. In the latter the crystals lie in all directions and have the maximum amount of space between them. By the addition of a suitable quantity of water, the molecules of which take their place between the grains of clay, the latter are enabled to change their places to obey molecular or poly-molecular attraction, and to move parallel to each other. This grouping is greatly assisted by the manual or mechanical kneading of the body, an increase of plasticity being observed every time a clayey body is subjected to mechanical treatment of a mixing nature. It is also clear that if a certain quantity of water is necessary to

allow the grains to become displaced sufficiently to give plasticity to the body, an excess of water—by driving the grains further apart—diminishes their attraction, and at a certain limit destroys the plasticity entirely.[1]

If a liquid other than water is mixed with finely ground clay, very different degrees of plasticity are obtained. Fatty liquids, such as oils, seem to make the body more plastic than does water, especially if the clay has previously been dried and so is devoid of hygroscopic water. On the other hand, alcohol, ether and turpentine produce bodies with little or no plasticity. On mixing a clay paste with glycerine, the water in the clay is gradually absorbed by the glycerine with the result that the clay loses its plasticity and becomes pulverulent.

If a clay paste is left in a dry atmosphere, the water evaporates in a progressive manner. As long as the body possesses a sufficient mobility, the departure of the water results in the grains of clay coming closer together in proportion to the volume of water removed. This diminution in volume of the body during the drying is known as its *shrinkage* or *contraction*. When there is not sufficient water to act as a lubricant and to allow the grains of clay to become displaced, the shrinkage ceases ; the evaporation of the remainder of the water induces the formation of voids in the interior of the mass.

The dry body, thus obtained, no longer resembles the original powder ; it forms a harder mass of greater density, the displacement and rearrangement of the grains of clays, as well as the shrinkage during drying, having sufficiently drawn the grains together to allow the molecular attraction to continue after the departure of water in spite of the voids. This is not the case with other mineral powders, which do not possess the lamellar form or colloidal nature of clay, and these, after having acquired a small amount of plasticity by their admixture with a liquid, fall to powder again when the liquid has evaporated.

A second shrinkage results during the firing, the product being a hard, amorphous body which constitutes the essential element of all ceramic products.

For further information on plasticity see pages 52 and 61.

Formation of Pure Clay.—According to the theory most widely accepted, pure clay is the result of the decomposition, under the

[1] Many ceramists do not accept this explanation as being complete, but regard plasticity as far more complex. According to one modern view, the colloidal film or gel which surrounds the particles of a plastic clay is sufficiently soft to allow the particles to flow over each other as though they were surrounded by a lubricant, yet it is sufficiently viscous to enable the mass to retain its shape when the shaping-force is removed. If this explanation is correct, only particles which are surrounded by a suitable quantity of a gel of appropriate consistency can be plastic and plasticity would be destroyed if the gel became harder (as a result of drying) or much softer (as a result of absorbing an excess of water). Moreover, it should be possible to make non-plastic particles by coating them with a suitable gel ; this has been done to a small extent by mixing a feebly plastic clay with a solution of gelatin in water or with other viscous fluids, but the products are far less plastic than a highly plastic clay.

influence of water and carbonic acid or other acids, of certain eruptive silico-aluminous rocks, the composition of which can be represented by the general formula—

$$RO, mAl_2O_3, nSiO_2,$$

mAl_2O_3 representing the alumina, sometimes mixed with a small quantity of ferric oxide (Fe_2O_3), and rarely with manganese oxide (Mn_2O_3); RO can represent the sum of the potash, soda, lime and ferrous oxide (FeO), and $nSiO_2$ the content of silica. The letters m and n are intended to show that the composition of the compound represented by the formula is not fixed and definite but may be variable. The most typical rock from which clay is derived is orthoclase felspar, $K_2O . Al_2O_3 . 6SiO_2$.

The decomposition which takes place may be represented very crudely by the general formula—

$$\underset{\text{(silico-aluminous rock)}}{RO, mAl_2O_3, nSiO_2} + \underset{\text{(water)}}{2H_2O} = \underset{\text{(clay)}}{Al_2O_3, 2SiO_2, 2H_2O} + \underset{\text{(silicate)}}{RO(n-2)SiO_2}$$

The silicate $RO(n - 2)SiO_2$ is generally decomposed into a silicate soluble in water and free silica.

Among the silico-aluminous rocks, which produce clays, the most important are felspathic rocks, granites, porphyry, gneiss, eurites, mixtures of felspar with quartz, and sometimes with mica. There are several varieties of felspar, the two principal of which are *orthoclase*, an anhydrous alumino-silicate with a base of potash, and *albite*, with a base of soda. The chemical formula for orthoclase is $K_2O, Al_2O_3, 6SiO_2$, or $K_2Al_2Si_6O_{16}$, corresponding to 65·4 per cent of silica, 18 per cent of alumina and 16·6 per cent of potash. The formula for albite is $Na_2O, Al_2O_3, 6SiO_2$, or $Na_2Al_2Si_6O_{16}$, or 68·57 per cent of silica, 19·62 per cent of alumina, and 11·81 per cent of soda. These two kinds of felspar are sometimes found mixed together.

In applying the preceding general formula to orthoclase it may be seen that decomposition might take place after the following manner :—

$$\underset{\text{(felspar)}}{Al_2O_3, K_2O, 6SiO_2} + \underset{\text{(water)}}{2H_2O} = \underset{\text{(clay)}}{Al_2O_3, 2SiO_2, 2H_2O} + \underset{\text{(potassium silicate)}}{K_2O, 4SiO_2}$$

Some chemists do not admit the formation of a substance with the formula $K_2O, 4SiO_2$ for an alkaline silicate resulting from the decomposition of the felspar, but state that the substance produced has the formula $K_2O, 2SiO_2$, the remainder of the silica being found in the free state, so that it can either remain mixed with the clay, or may be carried away by water at the same time as the alkalies.

This theory of the formation of pure clay by the decomposition

of felspathic rocks is confirmed by numerous examples of rocks, the decomposition of which continues to take place at the present time. When these rocks contain lime, calcium carbonate is also formed and is carried away by the water and deposited in sedimentary beds, forming numerous calcareous beds, occasionally of considerable thickness, as widely distributed as those of clay. The important part which the decomposition of felspar plays in the formation of sedimentary beds can be estimated by observing that nearly three-fourths of the known surface of the earth is formed of gneiss and granite containing 60 to 90 per cent of felspar.

The variations in the composition of these rocks, as well as in the circumstances of the decomposition, also explain the formation of other hydrous alumino-silicates—halloysite, lenzenite, severite, etc. —having a similar composition to kaolinite; allophane, which apparently corresponds to the formula SiO_2, Al_2O_3, nH_2O, pyrophillite, the composition of which is $5SiO_2$, Al_2O_3, H_2O, and a hydro alumino-silicate possibly $4SiO_2$, Al_2O_3, nH_2O, which is found in calcareous marls. It is also possible, as some geologists suppose, that some of these rocks may be distinct products of eruptive action.

Owing to the numerous rocks from which clays can apparently be formed and to the great variation in the composition of clays of different origins, it is extremely difficult to assign any definite composition to a hypothetical "true clay" which can be regarded as the essential constituent of all clays. It is far more probable that clays form a group of minerals of similar, yet somewhat indefinite composition, but characterized chiefly by a physical property—plasticity—which they all possess under certain conditions though to a very variable extent.

Slaking of Clay.—When a lump of dry clay is placed in a sufficient quantity of still water the clay gradually softens and eventually falls to a soft mud. If running water is used, the particles of clay, as they become detached from the lump, are carried away for a distance which depends on their size and specific gravity and on the velocity of the water.

This phenomenon is known as *slaking;* it serves to separate the coarse and fine particles in a crude clay and also facilitates the mixing of clay and water when preparing a plastic paste. It is characteristic of many clays that they form pastes with difficulty when they are in a damp state and are then "mixed" with water, but if they are first dried and then soaked in water they readily form a plastic paste.

(*b*) *Natural Clays.*

Formation of Natural Clays.—In some beds, clay is found mixed with the debris of the rocks which have produced it; in others the clay, instead of remaining intact in the place where it was formed, has been displaced by currents of water and carried to a distance,

where it forms sedimentary beds, more or less polluted by impurities also carried along by the water, this, the *first phase* of the formation of relatively pure clays, being characterized by the decomposition of silico-aluminous rocks, and the deposition of the substances thus formed on, or at a short distance from, the place of formation. These are termed *primary* clays. When pure they are termed kaolins, a name originally given by the Chinese (see p. 32).

The differences in the composition of the original rocks, as well as in the foreign matters which are found mixed with them, explain the considerable variations which are observable in the composition of primary clays, but these clays have properties by which they are easily recognized, especially when they can be separated in an approximately pure state by grinding and repeated decantation. Most of the primary clay obtained by this means is a whitish powder usually tinted yellow, light red, or grey, soft to the touch and slightly granulated, which, by the addition of water, forms a plastic body, emitting a characteristic earthy smell. Under the microscope it appears to be formed of a few thin, flat crystals of kaolinite, mixed with a very large, yet variable, quantity of amorphous particles and a smaller proportion of the debris of other rocks.

If the clay, instead of being simply displaced, is carried rapidly away by water, those materials in it which are loosened and held in suspension are taken along; jostled, tossed, pommelled amongst the pebbles, and end by being pulverized and transformed into impalpable mud, which is deposited in the mouths of the stream of water, or in parts where the speed of the water is reduced after having left the heaviest rocks on the way.

Sometimes when these currents of water have hollowed their beds in the midst of rocks which are too hard to be sensibly affected by their course, the materials in suspension have remained free from any mixture, and on deposition have formed beds of almost pure plastic clay, but in the majority of cases the torrents traverse sandy, calcareous, or ferruginous ground, or have mingled with water containing mud of various kinds. When still water is reached these materials previously held in suspension, are deposited simultaneously, forming beds of very varied composition, superposed by layers which also differ among themselves according to the circumstances attending the passage of the water. In this manner are formed sandy, ferruginous, calcareous, peaty, and other secondary clays.

This *second stage* of the formation of clays is characterized by the mechanical pulverization of the kaolin, or clay-rock, and the deposition of clays of the most diverse properties at a great distance from the place of original formation. In this second phase, the hydrous alumino-silicate, under the influence of mechanical pulverization in the water, undergoes important modifications. Under the microscope, its crystalline structure is no longer visible, and the material is composed almost exclusively of impalpable grains, is very unctuous to the touch, and variable in colour. On the addition of a suitable proportion of water a very plastic and flexible

body results, and this property easily enables clays to be recognized and distinguished from most other minerals. At the same time it must be realized that plasticity is a physical property which is largely independent of chemical composition, so that some highly plastic mineral substances, such as *bentonite* and some *laterites*, may be regarded as clays even though they differ very greatly from other clays in chemical composition.

Materials Mixed with Clays.—The materials which, mixed with " true clay " (as far as such a substance exists), form the numerous natural clays, can be classed under three divisions :—

(1) Undecomposed rocks, such as granite, porphyry, gneiss, quartz and mica.

(2) Other decomposition-products, as the carbonates of lime, magnesia and iron, various oxides of iron, etc.

(3) Other materials introduced by streams, etc., and deposited at the same time as the clay.

It is preferable, from a ceramic point of view, to substitute the following classification, based on the physical condition of the materials mixed with the clays :—

(*a*) Materials in impalpable grains which form an integral part of the clay, which it is impossible to separate from it by simple washing, such as various alumino-silicates, other silicates, mica, hydrated and quartzose silica, carbonates of lime, magnesia, oxides and sulphates of iron, organic matter, etc.

(*b*) Materials in fine grains which are distributed through the clay with a fair degree of uniformity, and are inseparable by slight washing, such as quartz, mica, felspar, carbonates or sulphates of lime or of magnesia, etc.

(*c*) Materials of various forms disseminated irregularly through the clay, but separable by washing or often even by sifting. These chiefly consist of accidental impurities, such as stones, shells, gypsum, sulphur, and iron ores. Calcareous clays cannot be used for bricks and tiles if the particles of limestone, chalk or other calcareous material are more than 0·04 in. diameter, because when the articles are burned the particles form lime and these tend to crack the articles or to " blow," leaving ugly white masses and hollows on the surface. If, on the contrary, the particles of calcareous material are very small they will not crack the articles in which they occur, but will merely form minute white spots which may be unsightly, but are harmless. Should the particles be sufficiently small and the firing temperature in the kiln sufficiently high, the lime will combine with the clay and will form spots of glassy matter which may be absorbed by the mass as a whole and so become unrecognizable.

To render clays containing calcareous material useful it is, therefore, essential that such material should be reduced to a fine powder. This cannot be done by crushing the pasty clay because the action of the machinery available for such clay is not sufficiently intense ; if, on the contrary, the clay is first dried (if necessary, by artificial

heat) and is then ground to powder, the particles of calcareous material can be reduced to any desired degree of fineness. By this means, if the colour of the resulting bricks is of minor importance, many calcareous materials which would, otherwise, be useless can be successfully employed in the manufacture of bricks.

Materials not Separable by Washing.—The *alumino-silicates and some silicates* in some clays are very difficult to recognize, because there is no method by which they can be separated. Le Chatelier sought to distinguish them by the temperature at which they are dehydrated and Mellor and others have endeavoured to distinguish them by the time-temperature graphs obtainable when heating them to 1200° C. Pukal and others have endeavoured to prepare these substances synthetically and numerous attempts have been made at the Carnegie Institute at Washington to endeavour to separate them by cooling various molten mixtures under different conditions.

Unfortunately, very little is yet known of these substances, which constitute the greater portion of the purer commercial clays, and whilst many ingenious theories have been proposed, the actual constitution of true clay and of the corresponding substance, or substances, in natural clays consisting wholly of extremely minute particles is not known.

Felspar and Mica.—It was at one time thought that the alkalies contained in clays were found exclusively in the state of impalpably powdered felspar, but Vogt has shown that this opinion is erroneous, and that they also exist in some clays in a state of equally minute particles of mica. He has proved that mica in coarse grains is not appreciably attacked by concentrated sulphuric acid, but it becomes so when reduced to an impalpable powder, so that when a clay is acted upon by this acid, both clay and mica are dissolved and are separated from the felspar and quartz. This distinction is somewhat important, since the pulverulent mica is plastic, whereas the felspar powder is not.

The variety of mica occurring in clays is chiefly a potassic mica, known as "muscovite."

Free silica occurs mixed with clay, either in the form of amorphous hydrated silica or as quartz or other forms of crystalline silica. The presence of hydrated silica in certain clays is not absolutely proved; it is usually found in extremely small proportions, has little or no influence on the plasticity and decomposes to form amorphous anhydrous silica at a temperature just above 100° C. Quartz or other forms of crystalline silica, on the contrary, is nearly always the result of the pulverization of the quartzose rocks. The coarser particles may be removed by washing or sifting, but some are so small that it is commercially impossible to separate them by this process. All free silica is, in itself, a non-plastic material.

Carbonates of Lime or of Magnesia.—Calcium carbonate mixed with clay may proceed from the decomposition and pulverization of limestone, or it may be deposited by water holding calcium bicarbonate in solution. Primary clays or kaolins do not usually

extract more than 2 per cent of carbonate of lime from such solutions, but secondary plastic clays can absorb 10 to 20 per cent of it. Calcium carbonate diminishes the plasticity, though to a less extent than quartz. Magnesium carbonate occurs in much smaller proportions in clays ; it originates in the destruction of magnesia rocks, and acts in many ways like calcium carbonate.

When these substances occur in grains of an appreciable size they are very injurious and render many clays unfit for use. During firing they become transformed into caustic oxides, which on cooling increase in volume by absorbing moisture and cause pottery containing them to split. Carbonates in clays are easily recognized by the effervescence which they produce when a few drops of acid are allowed to fall on them.

Iron compounds are found in clays, as anhydrous ferric oxide, as hydrated ferric oxide, ferrous carbonate, and as a complex ferrosilicate (*nontronite*) which is analogous in composition to kaolin. They are formed by the decomposition of ferruginous rocks, either by direct admixture or by penetrating into the clay in solution, in combination with organic acids such as " humus." The carbonate of iron can only exist in clay which is free from contact with moist air ; otherwise it is transformed into hydrated ferric oxide, the form in which it is chiefly found. The various compounds of iron colour the clay with different tints, chiefly yellow or red, the colour varying with the temperature to which the material is heated.

Iron compounds do not appear to diminish the plasticity of the clay, and they increase its cohesion after firing. Some clays contain 2 per cent or more of these substances. Beds of ferruginous clay may be deprived, entirely or in part, of the iron compounds they contain, if they are for centuries washed by waters containing organic acids in solution. This is the case, for instance, with the white clays of Vallendar, near Coblentz, and of Grossalmerode, in the Palatinate.

Sulphides of iron appear to be formed in beds of clay by the action, on carbonate of iron, of sulphuretted hydrogen, which is evolved from organic materials in a state of decomposition. These sulphides may be disseminated uniformly through the clay, but are usually found in groups or nodules.

Organic materials contained in clays may be derived from :—

(1) Infiltration of soil suspended in water into the bed of clay.

(2) The deposition of the clay in an estuary or marsh containing vegetable matter or to which such matter has access later.

(3) Various bituminous rocks which become mixed with the clay.

In the first and third cases, the proportion of organic matter is not usually large, but in the second it may become so. Generally speaking, organic substances tend to increase the plasticity, and greatly increase the quantity of water which the clay can absorb, and consequently its shrinkage. They are decomposed at a temperature below red heat and the carbon which remains is burnt off during the firing.

Various other impurities occur in small proportions in most clays. Many of them need not be mentioned, but the following are sometimes important :—

Free alumina occurs in some clays, in others the excess of alumina which has sometimes been found is probably due to silicates richer in alumina than is kaolinite.

Titanic acid, TiO_2, occurs in many clays and in nearly all fireclays to the extent of 0·5—2·5 per cent. It reduces the melting point of the clays in which it occurs, but is otherwise unimportant.

Clays sometimes contain, though in very small proportions, sulphate of lime, baryta, phosphoric acid, fluorine, and some metallic sulphides. On rare occasions, and then in very small quantities, compounds of vanadium, molybdenum, copper, chromium, and some gold (metal) occur. Seger attributed to vanadic and molybdic acids the yellow and green tints observed on some pieces of terra-cotta made from clays from the North of Germany.

Materials Separable by Washing.—*Felspar* only occurs in considerable quantity in primitive clays, in particles of laminated form which can be scratched by quartz. Orthoclase felspar fuses at about 1300° C., forming a milky glass (see p. 41).

Quartz, when in sufficiently fine grains, is a most excellent, non-plastic material. It mixes very well with clay, reduces the plasticity and shrinkage, and thus assists drying and firing the ware. Its grains are either rounded, or broken irregularly, very hard, slightly transparent, and infusible below 1600° C.

Mica is found in the form of very small and flat, but brilliant spangles, which remain for a long time in suspension in water. It introduces alkalies into the clay, in small proportion. It acts as a non-plastic material, but its laminated form disunites the clay and destroys the cohesion of the mass. Some impalpably fine mica is feebly plastic.

Coarser Impurities.—The coarser impurities sometimes found in clays, introduced accidentally or irregularly dispersed, are not as a rule mentioned in analyses, as they are often picked out during the sampling. In preparing clays for use, such impurities may be removed by hand-picking, or, if unimportant, they may be crushed to powder along with the clay.

Quartz or calcareous *stones* and *flints* may be separated either by hand or by suitable machines or they may be crushed to powder at the same time as the clay. Limestone is very objectionable, as it causes the articles to crack, but very finely divided chalk is harmless in this respect.

Shells, of which the calcium carbonate is very objectionable, contaminate many clays and shales ; they can only be removed by washing and then with difficulty. Sometimes there remains no more than the impression of the shell, the calcium carbonate being disseminated through the clay or having been washed out from it.

Gypsum is sometimes found in crystals of fairly large size, and in lumps which are easily separated.

Iron sulphides, which are formed in the clay, do not remain dispersed, but become agglomerated in the form of nodules or brilliant crystals of a fairly pronounced yellow colour, with a metallic lustre. When these are large they are easily removed, when they are small and numerous they are difficult to separate. For coarse products they may often be left in the clay, though the sulphur is volatilized in the kiln and the oxide of iron left causes the materials around it to fuse, thus forming cavities, and a blackish slag.

Iron ore, red hematite, and yellow limonite, are fairly frequent in plastic clays. The large pieces are easily separable ; the others may act like sulphide of iron or may simply stain the clay a red colour.

Classification of Clays.

The same difficulties are met with in the classification of clays as have been noted in the classification of pottery. The varieties of clays are extremely numerous, forming a continuous series from the hypothetical *true clay* to the very complex materials into which pure clay only enters in so small a proportion that there is some hesitation in classifying them as clays at all. As in the case of ware, it is expedient to avoid making hard and fast lines of demarcation, and to be content with mentioning the principal types without being unduly concerned with the exceptions. For these reasons, a classification of clays based on their geological formation, however interesting from a scientific point of view, has no value to potters, to whom it is much more convenient to consider clays in the state in which they are found and not the conditions of their formation.

Clays can be divided into two classes, *primary clays* or kaolins, which are feebly plastic, and *secondary clays*, which are more highly plastic. In primary clays, the grains, being relatively much larger, are less plastic, lighter and less unctuous to the touch than in secondary clays. The mere appearance and touch are often sufficient for a ceramist to distinguish a primary from a secondary clay.

Clays are distinguished by the nature and contents of the foreign substances mixed with the alumino-silicic acid or "true clay." From this point of view there is occasion only to consider five substances : silica, whose chief action consists in diminishing plasticity, and four others—alkalies, oxides of iron, lime and magnesia, which, with the possible exception of ferric oxide, increase the fusibility. Other substances occur in proportions too small to modify the properties of clay sufficiently to make it worth while to include them in a general classification.

Kaolins[1] (including the chief English kaolin or *china clay*) are chiefly found in the form of soft lumps in the midst of pegmatites,

[1] Many writers use the term "kaolin" in a general sense to indicate all comparatively pure clays, especially if they are but slightly plastic. China clay when refined is a typical kaolin in this sense. There are several objections to this use of the word *Kaolin* as it really indicates the place of origin and not the material (*kao lin* = a high hill) ; the terms "primary clay," for general use, and "china clay," for certain varieties, are more satisfactory, and these have been used where possible.

gneiss, granites, porphyry and other rocks. More rarely they are found in sedimentary deposits. It is only exceptionally that they can be used in their natural state, because of the rocky materials, often containing iron compounds, which are mingled with them. A careful sorting by hand is usually necessary, and this is followed by a process of washing, so that the natural products are not employed in the manufacture of pottery until they have been suitably purified.

The principal kinds of kaolin or primary clay are the following :—

(1) *Pure kaolins*, including *china clay*, do not contain more than 5 or 6 per cent. of free silica and 2 per cent of fluxes. They are always brought to this degree of purity by washing, and are sold in the form of a white powder, occasionally tinted faintly with yellow or red, and unctuous to the touch. After firing, the best qualities form a mass of milky whiteness. They are used in the manufacture of porcelain and fine earthenware and in several non-ceramic industries, such as the manufacture of paint and paper. The chief china clays in *England* are at St. Austell (Cornwall) and at Lee Moor (Devon).

(2) *Alkaline Kaolins or Primary Clays.*—The only difference between these and the preceding ones is a higher proportion of alkalies—up to 5 per cent—derived from felspar and mica. The proportion of oxide of iron is sometimes 2 per cent. These clays are used for earthenware and fine pottery. They can be purified by very careful washing, which removes the greater part of the alkalies, but are inferior to clays of the first group.

(3) *Silicious Primary Clays.*—In these clays the true clay is mixed with a considerable porportion of quartz or other form of free silica, in the state of impalpable powder, the proportion present depending greatly on the care bestowed in the washing. It may reach 20 or 25 per cent. These silicious clays furnish a body of small plasticity, and of a light granular texture ; they are used in the manufacture of porcelain and certain kinds of faience, where a very plastic body is not required.

(4) *Alkaline-silicious Primary Clays* contain a considerable proportion of both alkalies and silica, and partake of the properties and uses of the two preceding kinds.

(5) *Ferruginous Primary Clays* contain a proportion of oxide of iron which is so large as to prevent a white body being produced on firing, the iron acting as a staining agent. When the proportion of iron is not too high these clays are utilised in the manufacture of porcelain and faience of inferior quality. Those having a greater proportion of iron can be used in the manufacture of refractory products, if they do not contain too much alkali.

Secondary Clays.—The varieties of secondary, or plastic clays, being very extensive they may be divided into three classes :—

1. Refractory clays,
2. Vitrifiable clays,
3. Fusible clays,

which, as their names indicate, are distinguished by the manner in which the clays resist the action of heat.

Refractory clays are distinguished by a dull appearance without any sign of vitrification, which they preserve when fired at hard porcelain heat (1350° C.), or preferably at 1500° C. In Great Britain it is customary to consider as refractory all clays which when made into the shape of Seger cones do not bend when heated to a temperature below 1650° C. They can be divided into three classes :—

Pure clays, in which the alumino-silicic acid or true clay is mixed with only a small proportion of free silica and traces of fluxes. They are greyish-white, unctuous, plastic in a high degree, producing, after firing, a white body of fine " matt " texture. Those offered for sale have generally been washed ; they are used for the manufacture of fine faience and for some kinds of porcelain. The beds of these pure, refractory clays are relatively rare, and the variations in composition which are met with in the same deposit necessitate a careful sorting. Some carefully purified primary clays, such as some French and German kaolins and English china clays, may be included in this class of pure refractory clays.

Plastic refractory clays or fireclays are distinguished from the preceding by a slightly higher proportion of fluxes. The proportion of free silica can reach 20 per cent (or 57 per cent of total silica). They have usually a grey or yellow tint, and are rarely dark coloured. They are used in the manufacture of slightly coloured faience bodies and in that of refractory products. These beds are fairly numerous ; some are homogeneous and rich, others, on the contrary, necessitate a careful sorting.

Silicious refractory clays are distinguished from the preceding by a higher content of free silica, which may amount to 50 per cent, or about 73 per cent of silica in all. Their plasticity is naturally low, and their texture granular ; their use is generally confined to the manufacture of refractory wares. The colour is generally greyish, but is sometimes yellowish. The beds of these clays are fairly numerous. Siliceous materials containing more than 80 per cent of silica should not be termed *clays*.

Among the chief refractory clay beds (excluding china clay) in Great Britain are : Devon : Newton Abbot. Dorset : Corfe Castle, Wareham. Worcester : Stourbridge. Northumberland : Newcastle-on-Tyne, Durham. Yorkshire : Leeds, Elland, and near Sheffield. Lancashire : St. Helens. Wales : Aberdare. Scotland : Garnkirk, Glenboig, Kilmarnock.

Most of the coal-bearing areas in Great Britain contain fireclays, though some of these clays are of small value.

Vitrifiable clays are those which become vitrified or partially fused at porcelain heat (1350° C.), but usually remain porous at faience heat (1200° C.). They contain a higher proportion of fluxes than the refractory clays. They may be divided into plastic, ferruginous, and calcareous or alkaline clays, with intermediary

kinds, such as alkaline-ferruginous-plastic clays. Two of these varieties, from their use and the number of their beds, deserve particular mention :—

Vitrifiable alkaline clays, whether plastic or silicious, serve as a base for the manufacture of artistic stoneware, sanitary ware, and for chemical industries and paving tiles. Their colour is generally deep bluish, inclining to violet or grey, and on firing they give a body of which the tint varies from bluish-white to a deep, pearly grey, or from yellowish-white to brown.

Vitrifiable ferruginous clays are nearly always silicious, and can also be employed for the manufacture of sanitary stoneware, but are chiefly used for the making of paving tiles and vitrified bricks (*blue bricks*). They are of a yellow-red, orange-red, or brown colour, and produce a fired body of which the tint varies from brown to black.

Vitrifiable clays, as well as refractory clays, can be used in the manufacture of terra-cotta, providing that the temperature reached in the kiln is not too great.

The best-known beds of vitrifiable clays, almost all alkaline, in Great Britain are : Wareham, Newcastle-on-Tyne, Longport, South Yorkshire, and the Midlands. Excellent vitrifiable ferruginous clays occur in the Etruria marls of Staffordshire, and are used in the manufacture of *Staffordshire blue bricks*.

Fusible clays not only vitrify but lose their shape at a relatively low temperature, e.g. 1200° C. They always contain rather a large proportion of silica, but the constituents which cause them to fuse readily are lime, soda, and potash, which combine with the silica at a dull red heat, forming fusible silicates which melt when heated to a higher temperature. Substances which combine with another to form a fusible compound are known as *fluxes ;* thus, lime is a flux with silica and, conversely, silica is a flux with lime or soda ; the term " flux " is, however, usually restricted to the base, and is seldom applied to the acid oxide.

Most of these fusible clays do not melt completely below 1350° C., but a few do so at about 1050° C., and are useful as binding agents.

Some of these clays are sufficiently plastic for use in making pottery, tiles, etc., while others, being too friable, can only be employed in the making of plain bricks. Among the numerous kinds of fusible clay, four chief classes can be distinguished :—

Plastic ferruginous clays, very variable in colour, but generally rather dark, producing, on firing, an orange-red to brown mass.

Plastic calcareous clays, which effervesce in contact with acids, are very variable in colour, the fired body being white or orange to yellow, or brownish or greenish-yellow, according to the temperature. If the proportion of iron compounds is small, the fired clay may be quite white, as a result of the formation of a white iron-lime silicate.

Silicious ferruginous clays, of a very friable nature, which contain calcium carbonate, and so effervesce in contact with acids. They form wares having a similar appearance to plastic calcareous clays.

Fusible clays are very widely distributed, and are found in all countries.

2. Various Raw Materials.

Classification.—Materials (other than clay and water) which can enter into the formation of bodies may be divided into five classes, according to the purpose for which they are used :—

(*a*) Materials similar to clay, and can be substituted for it.

(*b*) Agglomerative and agglutinative materials intended to remedy a lack of plasticity in the body, and to act as binding agents.

(*c*) Opening materials used to reduce the plasticity of an excessively plastic material, or one with an excessively high shrinkage.

(*d*) Fusible materials added to increase the fusibility.

(*e*) Refractory materials intended to reduce the fusibility and make the body more resistant to heat.

(*a*) *Materials Similar to Clay.*

Clays can sometimes be replaced by other alumino-silicates which are slightly plastic, and harden under the influence of heat. According to Le Chatelier, however, these minerals are not definite silicates, but consist of true clay mixed with hydrates of silica or of alumina. The more important are :—

Halloysite, a white plastic material, of very variable composition, but containing usually 39 to 45 per cent of silica, 24 to 40 per cent of alumina, and 10 to 26 per cent of water. Halloysite has often been employed, but without great success, in the manufacture of French porcelain.

Lenzenite, a similar substance, is sometimes used instead of a fireclay, although it is not particularly refractory.

Collyrite and *allophane* contain, according to Le Chatelier, the same alumino-silicate, probably SiO_2, Al_2O_3, nH_2O.

Talc or *steatite* is found in the form of soft friable rock, of slight plasticity. In a pure state it is represented by the formula $4MgO$, $5SiO_2$, nH_2O, but its composition varies according to its origin. It has been employed for the manufacture of large ceramic vases and for parts of gas-burners, sparking plugs, and electrical insulators.

Magnesite—one form of magnesium carbonate—has been used in Spain for the manufacture of porcelain.

Giobertite—another form of magnesium carbonate—always mixed with a little silicate, is used as a refractory material, and for the manufacture of magnesic porcelain.

Asbestos is mixed with certain refractory materials, etc., because of its fibrous texture, for the purpose of producing a stronger mass. It is an anhydrous magnesium silicate containing lime and iron oxide ; its composition is very variable.

(*b*) *Agglomerative and Agglutinative Materials or Binders.*

In the manufacture of refractory wares from silica and other non-plastic materials, some form of agglomerant or binder is necessary. This may be either a *flux* or a substance which increases the plasticity of the material.

The chief fluxes are : Lime, iron oxide, calcium and magnesium chlorides, alum, and potassium and sodium carbonates. To these must be added calcium phosphate (bone-ash), in which both the lime and phosphoric acid act as fluxes, both boric acid and borax (see " Fusible Materials," p. 40).

When a body is not sufficiently plastic to bear shaping, and its chemical composition cannot be modified, artificial (or pseudo)-plasticity may be given by adding some viscous substance which will disappear during the firing. For this purpose, glue, gum, lichen, tar, dextrine, soap, sugar-molasses, or a mixture of soft soap and parchment glue, and of gum with soft soap, can be used according to the nature of the body and the ware required. Such agglutinative materials have been largely used in the manufacture of French soft porcelain.

(*c*) *Non-Plastic or Opening Materials.*

In order to reduce excessive shrinkage and yet retain the plasticity needful for the mode of working adopted, some clays must be mixed with non-plastic materials or—to employ a technical term—they must be " opened." From this point of view, a *lean* (or feebly plastic) clay is open compared with a *fat* (or highly plastic) clay.

The non-plastic or feebly-plastic materials used for this purpose may be divided into four classes :—

1. Silicious and sandy substances, including silicious or very lean clays.
2. Calcareous substances.
3. Carbonaceous substances.
4. Calcined substances.

Silicious Materials.—Silica not only serves as an opening material, but it acts either as a refractory material or as a flux. It occurs in several crystalline and amorphous forms.

Amorphous silica has a specific gravity of 2·2 to 2·3 ; it combines very easily with alkalies, and is produced by the decomposition of all silicates.

Crystalline silica has a specific gravity of 2·3 to 2·7, and is not easily attacked by alkalies. It occurs quite pure and abundantly in the form of quartz or rock-crystal, rarely as cristobalite and tridymite, almost pure in amethyst, chalcedony, quartzose rocks (felsites) and flint, and along with other materials in sands.

Silica combines at a low temperature with potassium and sodium compounds, and at higher temperatures with alumina, lime, magnesia, iron oxide, and most metallic oxides.

If quartz is heated several times, and for twenty to twenty-four hours each time, to the temperature of a hard porcelain kiln (1200° C. or above) the gradual progress of the transformation into other forms of crystallised silica (cristobalite and tridymite) can be traced. This change produces a corresponding modification in volume, as an equal weight of the recrystallized silica occupies a volume 16 to 17 per cent greater than quartz. This is of considerable importance in the manufacture of certain silicious wares ; it explains the swelling and destruction in firing of wares rich in silica, and when a suitable mixture of clay and silica is heated, no change in volume occurs, because the shrinkage of the clay is compensated by the increase in the volume of the silica.

When silica is used as an opening substance it is chiefly in the form of quartz, flint, and sand. The other forms are chiefly used as refractory materials.

Quartz occurs in quartzose rocks, granite, geniss, mica-schist, etc., but it cannot be extracted from these economically, and it is collected where these rocks have decomposed into their constituents. Before use it must be heated to redness and quenched suddenly in water. This treatment has the double advantage of transforming a part of the quartz into cristobalite, thus diminishing its tendency to swell subsequently, and of rendering the stone more friable and more easy to crush. The quenched material is then ground to a fine powder.

Flint is found in the form of pebbles in chalky ground. These pebbles are of all sizes ; they may either be picked directly from the surrounding chalk, or gathered on the seashore or at the mouths of certain rivers (as the Thames), where the tides are constantly breaking up the chalk cliffs. The most important source of flints is at the mouth of the Somme in France ; they are exported to England from Dieppe. For some unexpected reason, the flint pebbles from the corresponding English shore appear to be less pure and are unsatisfactory for pottery use. The flints are heated and quenched as described above, and are then ground to a fine powder, either in a dry state in ball mills lined with porcelain or stoneware to avoid contamination by iron, or by a wet method in pan mills.

Quartz and flint are only used as opening substances in the manufacture of fine pottery, particularly of fine earthenware ; for commoner ware sandstone or sand is used.

Sandstone is a term applied to several moderately soft rocks composed of compressed sand, the more highly silicious ones being used in the ceramic industries. The purer varieties may be regarded as " quartz," the less pure as " sand." They are ground to powder before use.

Sand is a product of the erosion of various silicious rocks. It has no definite composition, but is usually highly silicious, and is chiefly composed of quartz with varying proportions of felspar, mica, oxide of iron, carbonate of lime and clay, and with very small proportions of other minerals. When the total amount of

these materials does not exceed 2 or 3 per cent, the sand is said to be quartzose; it is termed felspathic, micaceous, ferruginous, calcareous, or clayey, whenever any one of these substances is present in a sufficiently large proportion.

Quartzose sand is an excellent opening substance; it occurs in the form of coarse or fine grains with either round or sharp edges. Sharp-edged grains are preferable to round ones, as the former mingle better with the clay and adhere more strongly to it.

Unless the sand is sufficiently pure it must be washed, as felspathic and micaceous sands introduce alkalies which act as fluxes. Grains of felspar are to be preferred to flakes of mica, and sand which is rich in mica must be either rejected or washed. Sand containing iron compounds is much employed for bricks, tiles and terra-cotta.

Calcareous sand should only be used when the lime in it is in an impalpable form. The injurious action of large grains of lime has already been noted (p. 31).

Clayey sand is an excellent opening substance, although more plastic than quartz; it has also the advantage of being more readily mixed with the clay of which the articles are made.

Saline sands introduce soluble salts into the ware, and produce, sometimes long afterwards, an objectionable efflorescence or "scum" on the surface.

For further information, see "Sands and Crushed Rocks," by A. B. Searle (Oxford Technical Press).

Calcareous Materials.—Calcium carbonate, especially in the form of marl (i.e. clay containing a large proportion of chalk or limestone powder), is sometimes used for opening clays, though the object of using this material is generally to obtain a more fusible body.

As opening substances, calcareous materials are undesirable, as they tend to make the ware liable to lose its shape during the firing. If calcium carbonate (e.g. chalk or limestone) must be added it should be in a very fine powder, and the ware should be fired at a temperature sufficiently high to cause it to combine with some of the silica and so form a harmless silicate. Any pieces of lime more than 0·04 inch diameter in the fired ware may swell, on exposure, and so crack the ware or "blow" and disfigure it.

Carbonaceous Materials.—In order to increase the porosity of fired ware it is sometimes convenient to mix the clay with some carbonaceous material which will be burned away during the firing and so will leave voids or pores in the ware. Many carbonaceous materials can be used advantageously—it is sufficient to mention coal and coke dust, cinders, sawdust, straw, lignite, spent tan, etc.; these materials also facilitate drying, diminish shrinkage, assist in the uniform distribution of the heat, and render the fired bodies more porous and "lighter," this last being often an advantage commercially. The ashes of all these substances form fusible silicates, and may produce unpleasant specks in the fired bodies.

Kieselguhr is sometimes used instead of carbonaceous matter to increase the porosity of a body.

Calcined substances such as *calcined clay* (often termed *grog*, *rough stuff*, and *grit*) may be ground to powder and used as opening materials. The grog made of calcined fireclay or china clay is excellent for this purpose, and has the advantage over quartz, flint, or sand of not swelling when heated, of not altering the composition of the body, of being easily crushed and sorted into grains of different sizes, and of giving a more permeable mass, so that bodies which have been opened by this means have a much greater resistance to sudden variations of temperature, a quality which is very important for certain refractory wares.

Grog is usually made by grinding fired bodies which have already been used, such as fireclay bricks, broken saggars, crucibles, etc., for which there is no further use, but in works which manufacture a large quantity of best refractory wares these sources are insufficient, and some clay must be specially calcined and crushed. The use of such grog is indispensable in the manufacture of highly aluminous wares, such as are used in the construction of kilns and of some of the appliances used in the chemical and metallurgical industries. The employment of sand would be inadmissible in this case, as it would unduly increase the proportion of silica. The temperature at which the clay should be calcined or fired depends largely on circumstances. Its plasticity could be destroyed by heating the clay to 400° C., but it is preferable to heat it to a much higher temperature—at least equal to that of the firing of the articles to be made from it—in order to diminish the shrinkage.

The size of the particles of grog is often important ; they should not be too small or they will not be effective, though unduly large pieces are equally objectionable. The usual sizes are less $\frac{1}{8}$ in. and larger than $\frac{1}{100}$ in., but for some articles a much smaller range in size is essential. The lumps are usually ground in an edge-runner mill, and the product is then passed over screens of various meshes.

Sherds, *shards*, or *pitchers* are sometimes used instead of grog ; they consist of broken pieces of the same ware which are ground to powder. The chief advantage of shards is that, whilst they reduce the plasticity and shrinkage of the clay, they do not alter the composition of the body. This is sometimes a matter of great importance.

Ashes are sometimes added to the clay used for making common bricks, but are inferior to sand and most other non-plastic materials, and are liable to discolour the articles in which they are present.

(*d*) *Fusible Materials.*

When raised to a sufficiently high temperature, which varies according to their composition and physical texture, clays gradually harden and become vitrified and impervious. It is often advantageous to lower the temperature at which this hardening and vitrification takes place, as more resistant wares can thus be obtained at a less cost for firing ; in earthenware the expansion of the body

can be modified and made to correspond with that of the glaze, and in other wares the risk of distortion during the firing is reduced.

To secure these effects either a *fusible substance* may be added to the body so that the melting-point of the mixture is reduced, or a *flux* (p. 37) may be added which will combine with some of the silica or clay in the body, and so form a fusible substance *in situ*. The chief fluxes are mentioned on page 37. They may be divided into alkaline, calcareous, magnesic, ferric, and phospho-calcareous fluxes.

Alkaline Fluxes.—Alkalies (a generic term for most compounds of sodium and potassium, but often including lime and magnesia) may be introduced into bodies in three different forms :—

(1) As salts, derived from vegetable ashes or produced by the manufacturers of various chemicals.
(2) As silicates, artificial borates, or "frits."
(3) As felspars and felspathic rocks.

Alkaline salts are not employed directly, as such small proportions of them are needed to increase the fusibility of the clay that their homogeneous mixture with the body is difficult and uncertain. Carbonates are sometimes used, but are objectionable because of their solubility, and because the carbonic acid which they evolve during the firing tends to inflate the mass. Sulphates are also used, but they evolve sulphur trioxide, which is objectionable, and also require a high temperature for their decomposition.

Frits are in constant use in the manufacture of glazes, though they are little used in body-mixtures (see Chapter VII). They are made by heating a mixture of silica and alkaline salts, the glassy substance produced being then finely ground. Frits are sometimes replaced by *glass* which, because of its low price, can be used in the manufacture of common stoneware.

Felspar and *felspathic rocks* are the most popular raw alkaline fluxes. They are widely distributed, but require careful selection if they are to be pure enough to be of use. Their colour is no sign of purity, as some white felspars become yellow, red, or black at a high temperature, while others which are strongly coloured when found become white on heating. Felspars are heated strongly, and reduced to a fine powder, which is the form in which they are found in commerce.

Felspars are silica compounds of alumina and alkalies, chiefly potash and soda. They generally contain a small proportion of iron oxide, lime, and magnesia, though in some felspars the quantity of lime is too large to be neglected. Norway supplies the felspar used in the chief European potteries.

Among felspathic rocks, *pegmatite* is the most in use. It is largely employed in France, where there are important beds at St. Yrieix, and in England, where it is known by the name of *Cornish Stone*, as it is found in Cornwall.

Porphyry, trachytes, basalt, and other analogous rocks have sometimes been utilized. Their composition is generally very variable.

Calcareous fluxes are those whose essential constituent is *lime*, which is introduced into bodies as a flux in the state of calcium carbonate, sulphate or silicate.

Calcium carbonate or *carbonate of lime* can only be used as a flux when the temperature of firing the pottery is sufficiently high to decompose and eliminate the carbonic acid. At lower temperatures it only serves as an opening substance. In making " mixtures " it must not be forgotten that there are in 100 parts in weight of carbonate, 56 of lime and 44 of carbonic acid, and that only the lime acts as a flux.

Deposits of calcium carbonate are very numerous. White *marble* and *chalk* are almost pure carbonates ; *limestones* and *marls* are also used.

Marls are mixtures of calcium carbonate and clay. According to Le Chatelier and Vogt, the latter is not true clay, but corresponds with the formula Al_2O_3, $5SiO_2$, nH_2O. The composition of marls is very variable. *Calcareous marls*, containing from 20 per cent to 40 per cent of alumino-silicic acid (clay), are distinguished from *clayey marls*, in which this proportion reaches 70 to 80 per cent. Marls nearly always contain 2 to 8 per cent of iron oxide.

The plasticity of marls depends on the proportion of silica and alumina (clay) present, so that, generally speaking, clayey marls may be considered as relatively plastic substances, and calcareous marls as opening ones and fluxes.

Calcium sulphate or *sulphate of lime* (plaster of Paris, gypsum) can only be used in pottery fired at a high temperature, because it is only decomposed with great difficulty. Its only advantage over calcium carbonate is its slight solubility in water, which allows it to be mixed more easily in bodies. It must not be employed simultaneously with a large proportion of alkalies, or it may form alkaline sulphates, which are still more difficult to decompose. Calcium sulphate should be calcined before use in order to eliminate the water it contains. Some forms of calcium sulphate contain impurities, such as clay, iron oxide, gravel, calcium carbonate, strontium, sulphate, etc. ; these should be avoided.

Calcium silicate or *silicate of lime* occurs in the slag from blast furnaces. It also contains aluminium silicates, and frequently iron oxide, magnesia, manganese, and various sulphates and sulphides. This very variable and very impure material is used in the manufacture of the kind of floor-tiles known as " quarries," stoneware, and imitation stone.

Magnesia can be mixed with bodies either in the form of *dolomite* (a double carbonate of lime and magnesia), as magnesium carbonate (*magnesite*), or in the form of *talc* (a magnesium silicate). Magnesic fluxes are used for the manufacture of some porcelain ware, and sometimes enter into the composition of glazes. They produce very viscous silicates with a long range of vitrification, i.e. a great difference between the temperature at which the first signs of fusion occur and that at which the material is completely fluid. In this respect they

are superior to the calcium silicates, which have a very short range of vitrification, and tend to excessive distortion of the ware in which they occur.

Iron Fluxes.—The only oxide of iron which acts as a flux is the ferrous oxide (FeO), but the red oxide (Fe_2O_3) and the black magnetic oxide (Fe_3O_4) can be reduced to the ferrous state under certain conditions of firing (e.g. when there is not sufficient air) and then act as fluxes, as in the manufacture of blue bricks and tiles. In an oxidising atmosphere, the red ferric oxide (Fe_2O_3) is almost infusible, and its action is similar to that of alumina ; it is only added to bodies for the purpose of colouring them red or brown, unless it is intended to fire under reducing conditions and so produce ferrous oxide as a flux.

Phospho-calcareous Fluxes.—Calcium phosphate (*bone-ash*) is generally made from the bones of animals, but native phosphorite may be used. The bones employed are chiefly those of the ox, those of horses and pigs being rejected because they give colour to the body. The bones are dried, cleaned by boiling in water, calcined until they are entirely white, and then finely pulverized.

Phosphorite is a natural fibrous stone, containing up to 93 per cent of calcium phosphate.

Bone ash is used chiefly, if not exclusively, in England in the manufacture of the soft porcelain known as *bone china*.

(*e*) *Refractory Materials.*

The chief refractory, or heat-resistant materials used in the preparation of pottery bodies are *kaolins* (including china clay) (p. 32) ; *fireclays*, especially those of the Coal Measures (p. 34) ; *silica*, chiefly in the form of ground quartz, flint, or sand (p. 38), but occasionally—when high porosity and low relative density are required—in the form of *kieselguhr*, *infusorial earth*, or *diatomite*, which is very light, its weight being less than that of an equal volume of water. It is composed of tiny cells consisting almost wholly of silica, but its composition varies greatly ; the silica has always a specific gravity of 2·2 to 2·3. As in this form it lends itself better to the formation of multiple silicates, it is less refractory than quartz. Its exceptional lightness renders it very useful in the manufacture of filters and of the refractory articles employed in the fire-boxes of locomotive and marine boilers. It is also of great value as a heat-insulating material.

Gannister is the name given to a grit-stone in England and the United States, which is found at the base of the carboniferous system ; it can be used either by itself or mixed with a refractory clay. Its composition resembles that of a mixture of silica with 5 to 10 per cent of clay.

Alumina can be introduced into bodies in the form of alumino-silicic acids and silicates more aluminous than clay, or as *bauxite*, a crude aluminium hydrate of very variable composition, often mixed with a large proportion of iron oxide.

For further information, see "Refractory Materials: their Manufacture and Uses," by A. B. Searle.

3. Testing Raw Materials.

(*a*) *Testing Clays.*

Methods of Testing.—The tests to which clays can be subjected are of two kinds: (*a*) chemical and (*b*) physical or mechanical.

The object of chemical tests is to determine the composition of the clay and of the various materials which may be mixed with it.

(i) The composition of the clay can be investigated, and the nature and composition of the other mineral substances in it determined.

(ii) The ultimate composition may be ascertained by means of an analysis without any account being taken of the form in which the various substances disclosed by the analysis are combined.

(iii) The presence and, if present, the proportion of a certain substance in the clay may be ascertained.

The object of physical or mechanical tests is to determine the chief physical properties either in an absolute manner or by comparison, such as :—

(*a*) Determination of the texture of the clay, and particularly the coarseness of the grains which constitute it.

(*b*) Measurement of the plasticity and of the shrinkage during drying and firing.

(*c*) Tests of the fusibility, porosity, and shrinkage of the clay at different temperatures, or under different conditions.

Tests of the Constitution of Clays.—Unfortunately, tests made to ascertain the constitution of clays have still the character of scientific researches, and are but little use to the manufacturer.

A preliminary removal of sand and other coarse-grained materials from a clay may be effected by *washing*—a process which is largely used, but it is difficult to know to what point the washing shall be carried, and the suggestion that all grains less than $\frac{1}{100}$th of a millimetre diameter shall be considered as clay is objectionable, as many materials mixed with clay (such as silica, alumina, lime, and iron oxide) can be found in the form of a powder which is so fine that it cannot be separated from clay by any mechanical process. Washing should, therefore, only be considered a means of determining the texture of the clay, and as giving a rough guide to its impurities, and not as a method of exact analysis.

In the present state of chemistry the best process by which information on the constitution of clay can be arrived at consists in first purifying the clay as far as practicable by washing or elutriation (p. 50), and then submitting a known weight of the dried and purified clay to the action of boiling sulphuric acid. The clay, reduced to as fine a powder as possible, is placed in a platinum crucible and kept immersed in dilute sulphuric acid for several hours at a temperature of about 100° C.; any carbonates of lime

and magnesia, hydrated oxide of iron, etc., are dissolved, and can be separated according to the general methods of analysis. The residue, after being duly filtered, washed and dried, contains the clay, insoluble silicates, and free silica. It is returned to the platinum crucible, and subjected from fifteen to twenty hours to the action of boiling concentrated sulphuric acid. Any alumino-silicic acid (clay), as well as any powdered mica, are attacked and dissolved, and the residue is composed of free silica (quartz), coarse mica, and felspar, and can be separated by cautious dilutions with water followed by filtration. The treatment with acid should be repeated on the residue until the weight remains constant. In this way the weights of true clay, mica, free silica (sand, quartz), and felspar in the clay are obtained.

There is no process for the separation of clay from mica, and one must be content with analysing the mixture, and assuming the composition of the mica to be potassic mica (muscovite), multiply the proportion of alkalies found by 8·5 to convert it into mica; the corresponding amounts of alumina and silica are calculated and deducted from the amounts found in the residue. Any alumina left is multiplied by 2·53 to convert it into "true clay" ($Al_2O_3 . 2SiO_2 . 2H_2O$, the formula for kaolinite). Any silica in excess of 1·176 times the alumina is assumed to be present as free silica. The composition of the portion of the clay soluble in concentrated sulphuric acid will then be reported in terms of mica, "true clay," and free silica. The assumptions as to the compositions of the mica and "true clay" may not be correct, but the method is a convenient one, and is often sufficiently accurate.

The residue left undissolved by the concentrated sulphuric acid, and composed of quartz, felspar, and coarse mica, can be again "washed" or elutriated, because, on account of its lamellar form, the mica remains for a longer time in suspension in water. A mixture of quartz and felspar is then obtained which it is impossible to separate mechanically, though from an analysis of it the amount of free silica and felspar could be calculated by multiplying the potash by 5·914, i.e. by assuming the felspar to be orthoclase.

This process is often used and is very convenient, but the results obtained with many clays are far from accurate.

The determination of the quantity of water removed on heating a clay to increasing temperatures also gives information as to its constitution. In heating a clay to 110° C. until two successive weighings, made an hour apart, indicate no further diminution of weight, a figure is obtained which includes the hygroscopic water, the water from the hydrated silica, iron oxide, and the more volatile parts of some organic substances. If this heated clay is then left for about ten days under an inverted glass vessel in a moist atmosphere, its increase of weight will indicate the proportion of hygroscopic water alone.

Again, on heating clay—previously dried at 120° C.—with air for a fairly long time at a temperature from 600° to 700° C., the

further loss of weight which will be observed corresponds to the water in the alumino-silicic acids (clay) and hydrosilicates, aluminium, hydrate, and to the carbon, etc., of the organic materials. By repeating the same operation in a hermetically sealed crucible, or, better, in a tube traversed by a current of carbon dioxide, the combustion of the carbon is prevented, and its weight can then be obtained by observing the difference between the two results. The temperature must not be raised above 700° C. or the decomposition of carbonates would take place. For many purposes the loss on weight which occurs when a clay is heated at 700° C., in a current of carbon dioxide or *in vacuo*, is sufficiently near to the amount of combined water in the clay that it may be used to calculate the proportion of " true clay " present ; this is done by multiplying the loss in weight by 7·1.

Chemical Analysis.—The " ultimate " chemical analysis of a clay requires much skill and practice in order that it may be carried out properly ; the results are often of great importance. The following is an outline of the method most used :—[1]

One gramme of the clay, which has previously been reduced to powder and dried at 120° C., is weighed accurately and mixed with five or six times its weight of sodium carbonate, which has been previously pulverized. The mixture is placed in a platinum crucible and heated until it is completely fused. After cooling, the crucible is placed in an evaporating dish and distilled water added and boiled until the material is completely dissolved. The contents of the crucible are then rinsed into the dish. Hydrochloric acid is added drop by drop, until all bubbling has ceased. The dish and its contents are heated slowly, so that all the water is evaporated without any " spitting " and the solid residue is maintained for two hours at about 105° C. It is allowed to cool, and a little hydrochloric acid is again added, and the mixture is heated up to boiling, after which the liquid is diluted with water, boiled, and filtered through paper. The silica remains on the paper while the bases and alumina are in solution as soluble chlorides. When every particle of silica has been placed on the filter it is well washed and then dried and calcined : the weight of the residue, less that of the paper-ash, gives the weight of the silica contained in the weight of clay tested. To confirm this it is well to add a little hydrofluoric acid and sulphuric acid to the silica, to heat it until all the acid is volatilized, and afterwards to weigh the crucible. If its weight shows that any residue is left, it should be fused with a little potassium bisulphate dissolved in water and added to the solution previously obtained. Meanwhile the weight of the residue should be deducted from that of the silica. If the residue is large it is well to re-fuse it in sodium carbonate, and to treat it with acid as before, as a large residue may imply that the original fusion was incomplete.

The liquid which has passed through the silica filter is diluted

[1] It must not be supposed that all the precautions necessary for accuracy are given.

with water to a convenient volume (say 500 c.c.) and is divided into two equal parts.

Into the first, ammonia is poured until the liquid becomes slightly alkaline ; the liquid is boiled until almost all the ammonia has evaporated, and the liquid (containing a precipitate of alumina and iron hydroxide) is allowed to remain for several hours in a warm place. It is then poured on a filter ; the residue is washed carefully with warm water, and the filter is dried, calcined, and weighed. The weight obtained is that of the alumina plus iron oxide. The filtered liquid is heated until its volume is reduced by one-half, and an excess of a warm solution of oxalate of ammonia is added. This forms a precipitate of calcium oxalate, which is, in due time, filtered, washed, dried, and calcined to redness, to convert the oxalate into caustic lime, then rapidly weighed ; this gives the lime present. Lastly, the filtered liquid is cooled and treated with ammonia and a solution of phosphate of soda. Magnesia is precipitated in the form of ammonium magnesium phosphate, which, after standing all night, is filtered, dried, calcined, and weighed in the form of pyro-phosphate of magnesia. The weight of the pyro-phosphate, multiplied by 0·362, gives the weight of magnesia present.

The second part of the liquid preserved after the elimination of silica is employed for the determination of the iron oxide. It is placed in a flask and, whilst boiling, small pieces of pure zinc are added until the liquid from being a melon colour becomes colourless and all the iron is in a ferrous condition. Any surplus zinc is removed and a standard solution of permanganate of potash is added, drop by drop, from a burette ; the liquid remains discoloured so long as there is any iron in the form of ferrous oxide, but directly the whole of the iron is transformed into ferric oxide the liquid assumes a pink tint. The volume of the permanganate solution so used is proportional to the amount of iron present, and knowing its strength the amount of iron can be calculated as ferric oxide. This amount, deducted from the "alumina plus iron oxide" previously found, gives, by difference, that of the alumina.

If any titanic oxide is present, part of it will be precipitated with the silica, and will remain in the residue after the silica has been volatilised with hydrofluoric acid. If this residue is fused with potassium bisulphate, as directed, the titanic acid will all be precipitated with the iron oxide and alumina. It can be determined in part of the liquid set aside for the determination of the iron oxide by adding hydrogen peroxide and comparing the colour produced with that of various quantities of a standard solution of titanium sulphate when an equal amount of peroxide is added.

When it is desired to determine the alkalies—as ought always to be done—an accurately weighed portion of the very finely pulverized clay is placed in a platinum crucible, and mixed with pure hydrofluoric acid.[1] After some hours of heating, sulphuric acid is

[1] If preferred, Lawrence Smith's method (fusion with ammonium chloride and calcium carbonate) may be used.

added, and the liquid is evaporated to dryness. All the bases are then in the form of sulphates ; they are dissolved in warm water, and if the operation has been well carried out, no residue should remain. On treating this solution with baryta-water the alumina, oxide of iron, lime and magnesia are precipitated together with barium sulphate. The liquid is filtered, ammonium carbonate is added, and the liquid is again filtered. The liquid is then evaporated and calcined to volatilize the ammonia salts. It is then treated with water, and with ammonium carbonate, in order to ensure the complete precipitation of earthy bases. After filtration, fresh evaporation of the solution and a slight calcination, the alkalies are dried and weighed in the form of carbonates, or a little sulphuric acid may be added after the calcining and the latter repeated, when the alkalies will be weighed in the form of a mixture of sodium and potassium sulphates. The mixture is dissolved in acidulated water and heated slowly almost to dryness, redissolved in 10-15 c.c. of hot water, and two or three times as much perchloric acid as is theoretically required is added to precipitate the mixed perchlorates. The mixture is evaporated to a fuming syrup, allowed to cool slightly, taken up with hot water, 5 c.c. more perchloric acid added, and the liquid re-evaporated until it fumes. The syrup is allowed to cool, and about 20 c.c. of almost absolute alcohol is added and well stirred. The insoluble matter is allowed to settle and is then filtered through a Gooch crucible, washed with a little of a mixture of ether and alcohol, dried at 120° C., and weighed as $KClO_4$. The weight multiplied by 0·34 gives the equivalent weight of potash K_2O. The soda (Na_2O) is taken by difference.

Special Tests.—Special tests are employed when it is simply desired to know if, and in what proportion, a certain substance exists in the clay.

The most simple of these estimations is that of hygroscopic water, or *moisture*, the amount of which may vary greatly in the same clay, so that sometimes account must be taken of it. This is determined by heating a given weight of the powdered clay to 110° C. until two consecutive weighings, made at an interval of an hour between each, during which time the clay has been kept at the temperature mentioned, show no further loss of weight.

It is often very important to know whether a clay contains *iron oxide*, and if so in what proportion. This can be ascertained without difficulty by boiling 50 grammes of the finely powdered clay with sulphuric acid diluted with two or three times its volume of water. After having allowed the mixture to remain for twenty-four hours, it is again diluted with water and filtered. The liquid thus obtained is placed in a flask and heated, some pieces of pure zinc being added at the same time. All the iron is reduced to protoxide, and it is treated with a solution of permanganate of potash, as already described. Or the presence of iron may be confirmed by adding an excess of ammonia to the clay after it has been treated with sulphuric acid, diluted and filtered as described above. If there is

any iron in the clay, the ammonia will form a brown precipitate in the case of iron peroxide, or a darker precipitate which turns brown in contact with the air if the iron is in the form of protoxide. As alumina is also precipitated as a white material, this test cannot be used to estimate the amount of iron present. Some clays require to be fused before solution.

Lime is another substance which it is important to recognise in clays, especially when it exists in the form of carbonate. This is done very simply by pouring an acid (sulphuric, hydrochloric, or nitric acid) on to the clay. If it produces an effervescence of carbonic acid gas this is a proof that the clay contains some carbonate, most probably lime, and its proportion can be roughly estimated according to the intensity of the effervescence. If an accurate knowledge of the amount of lime present is required the clay must be subjected to an ultimate analysis as already described. For calcareous clays, the following process can also be employed: in a light flask are placed 10 grammes of powdered clay, and this is diluted in water and the mixture stirred; into a second flask, which must also be light, are poured about 10 grammes of acid, which is diluted with from two to three times its volume of water. The two glasses are then placed on the pans of a balance and weighed. The contents of the second glass are poured into the first, drop by drop, very slowly, so as to avoid a strong effervescence or a considerable heating of the liquid. When the ebullition has ceased the glass is warmed and shaken in order to liberate the bubbles of carbon dioxide gas. The two flasks are replaced on the pan, the difference in weight which indicates the proportion of carbon dioxide contained in the clay is determined, and the proportion of calcium carbonate is deduced from this by multiplying the loss in weight by 2·28. For very accurate work a special form of flask may be used. If the clay contains volatile organic substances, this process is not applicable.

The proportion of *soluble salts* contained in a clay can be roughly determined by heating a weighed quantity of clay (30 grammes) for one hour in boiling distilled water. The mixture is poured on a filter, and the clear filtrate is evaporated to dryness, and the residue weighed. It can be analysed according to the general methods. The objection to this method, as published, is the difficulty in obtaining a perfectly clear solution. Some clay nearly always passes through a paper filter, but Mellor has shown that an unglazed porcelain crucible operated under a partial vacuum is a perfectly satisfactory substitute.

Tests for Fineness.—Ordinary clays are formed of extremely small grains of true clay mixed with other grains of various sizes, depending on the nature and proportion of the other materials entering into the composition of the "clay." A microscope enables the form, and often the nature, of the coarsest grains to be recognized, but its indications are insufficient to show the nature of the smallest particles.

The separation of the coarser grains according to their size may be effected with a series of sieves, but the finest grains cannot be so separated, sifting therefore gives incomplete results, and for the finer particles it is replaced by *elutriation*. This may be done in two ways: (1) The clay may be placed in suspension in water, stirred strongly, and then left to settle. The coarsest grains sink rapidly, then the medium sized, and finally the finest particles remain for a long time in suspension, and do not settle for several hours, or even for several days. If the process is carried on in a graduated test glass, the number of divisions can be read which correspond to the volume of each size of grain. This method is very simple, but the results are inexact, because the particles which are at the bottom of the test glass at the moment of agitation remain mixed with the coarser grains. Moreover, the reading of the divisions is necessarily inaccurate, and it is therefore better to have recourse to the second method, which is more complicated, but more precise. It consists in submitting the clay to a continuous current of water, the speed of which can be regulated at will. It will be understood that, with a low speed, only the finest particles are removed, but with a greater speed the medium-sized or the coarsest particles are carried off. Several different forms of apparatus have been constructed on this principle; in that proposed by Schulz (Fig. 1) the clay is placed in a glass into which the water runs from a high reservoir, the speed being regulated to carry off all except the coarsest grains. The particles so removed are brought into a second glass, which has a larger diameter, and where, consequently, the speed of the current diminishes and allows the largest grains still in suspension to settle. The same takes place in a third glass, larger than the second, and finally only the finest particles reach the lowest reservoir, where they settle. At the end of the operation the water in each glass is poured off, and the residues contained in the different glasses are separately dried and weighed.

The apparatus shown in Fig. 2, invented by Schoene, gives better results. It consists of a conical tube AD, 23-25 in. high, the diameter at B (2 in.) being reduced to 0·20 in. in the tubes DG and AL. A little water is poured into the tube AD. A known weight of the clay to be tested is then mixed into a slip with water, and the mixture is poured into the tube AD, through the opening A, from which the india-rubber stopper has been removed, and water is added until the liquid reaches the mark C. The stopper, with the tube AL, having been replaced, a stream of water is made to enter the apparatus at G, and makes its exit by a small orifice K. The speed of this current is measured by the height of the water in the tube KL, which is about 5 ft. long. The flow of the water is regulated by a tap, and it is arranged that the level of the water rises, e.g. to 0·71 in. in KL, the stream of water then taking away the grains of less than 0·00039 in. diameter, which are collected in a receiver placed under the orifice K. When the water has become clear the speed is increased, the particles in suspension are collected in a

second receiver, and the operation is thus continued until the greatest speed is reached which the current can obtain by this apparatus, the particles then remaining in the tube being at least 0·0156 in. diameter. The contents of the various vessels are allowed to settle, the water is poured off, and each residue is dried and weighed. In

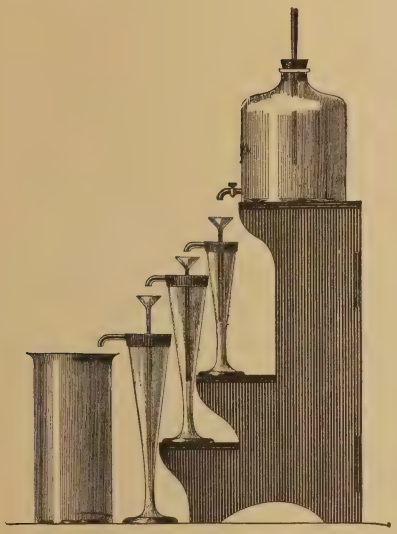


Fig. 1.—Schulz's levigating apparatus.

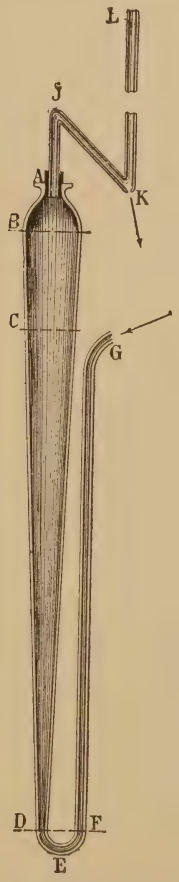


Fig. 2.—Schoene's elutriator.

order that the orifice K may not be choked, it is necessary to first pass the clay-slip through a sieve with 100 holes per linear inch.

According to Seger, the different sizes of grains may be classified as follows :—

(1) Grains of less than 0·00039 inch are considered as *clay*. This should be confirmed in important cases by an analysis of the material, for though the ultimate composition of these grains is remarkably constant they are not necessarily clay.

(2) Grains of 0·00039 to 0·00098 in., showing a certain amount of plasticity when held between the fingers, but yielding a mass which disaggregates on drying, are regarded as *silt*.

(3) Grains from 0·00098 to 0·00156 in. diameter, having little or no plasticity, but the different grains of which are not perceptible to the touch, are termed *dust sand*.

(4) Grains from 0·00156 to 0·0118 in. form *fine sand*.

(5) Grains above 0·0118 in. are regarded as *coarse sand*.

Tests of Plasticity.—The plasticity of a clay depends *inter alia* on (see p. 61) :—

(1) The plasticity of the "true clay" which it contains.

(2) The proportion of this "true clay" relatively to other materials.

(3) The proportion of colloidal (gel) matter present.

(4) The nature, size, and the shape of the grains of these materials.

Thus, a chemical analysis, the proportion of alumina or of hygroscopic water, and the result of washing tests can never serve as a true measure of plasticity, and it is necessary to use direct mechanical tests. The most simple of these consists in moulding the clay by hand, and estimating the plasticity by touch. However primitive this may be, it must be confessed that it is nearly always sufficient. To facilitate the comparison of clays among themselves, the following process, by Bischof, may be used, though it measures the binding power rather than the plasticity :—

A quantity of clay is dried at 110° C., and is divided into several parts all having the same weight, e.g. 50 grammes. A weighed amount of fine, dry quartzose sand is added to each part of clay in increasing quantities. An intimate mixture of the sand and clay is made, water is added to form a body which can easily be shaped by hand, and a series of pellets are fashioned, and left to dry. When the drying is complete these pellets are placed above a piece of white paper, and rubbed between the fingers and thumb. If the proportions of sand have been suitable, the pellets which have the least sand in them remain intact, those which have the most are completely rubbed away, and an intermediate pellet is eventually found which forms the limit, only a small quantity of grains being detached by the rubbing. The proportion of sand which this pellet contains is made to serve as a measure of the plasticity. In order that the tests may be comparative, the same sand must always be used. The quantity of sand which can be mixed varies from 0 to 3 times the weight of clay, according to its plasticity, and each pellet is made by adding $\frac{1}{10}$ more of its weight in sand than the preceding one. If, therefore, a clay has been able to absorb $1\frac{1}{2}$ times its weight of sand, its plasticity will be represented by 1·5. A good pottery body will usually absorb from once to twice its weight of sand.

It has also been proposed to determine plasticity by forming test-pieces having the shape of those used for testing cements, and measuring the force required to break them. As clay shrinks it is

necessary to measure the reduced section and to divide the weight which has effected the breaking by the surface thus found in order to have the effective resistance per square inch. It must, however, be admitted that although the figures thus obtained are interesting, they do not necessarily measure the plasticity.

Zschokke has obtained better results by multiplying the force thus used for breaking by the percentage of extension. The whole subject of the measurement of plasticity is discussed fully in *British Clays, Shales, and Sands*, by A. B. Searle, and in *The Chemistry and Physics of Clay*, by A. B. Searle.

Tests of Refractoriness are made to determine the manner in which a clay behaves under the influence of an increasing temperature. These tests ought, strictly, to show the progressive changes in the porosity and shrinkage of the clay or body at different temperatures or under various conditions of heating, the temperature at which it begins to vitrify, that at which it first begins to soften and lose its shape, either naturally or under the influence of a load or pressure, and, finally, that at which it melts. The changes in these properties at different temperatures will, if recorded in the form of graphs, often afford invaluable information respecting the behaviour of clays. The temperature of true or complete fusion of clays has no practical interest, and the term "fusibility" is therefore commonly used to mean the temperature at which the body loses its shape. This subject is dealt with in Chapter VIII, on "Firing."

Attempts have been made to replace direct tests for the fusibility and refractoriness of clays by calculations deduced from the chemical composition. Thus, the molecular ratio of the fluxes to alumina, and of alumina to silica, was supposed by Bischof to be inversely proportional to the fusibility, but this only applies to clays which are highly refractory, and even then is not reliable. Ludwig obtained a much better and wider method of calculation by the use of a graph in which the clays are reduced to a formula with Al_2O_3 as unity, the RO bases being then taken as ordinates and the silica as abscissæ. (See *Refractory Materials : their Manufacture and Use*, by A. B. Searle, for further details.)

(*b*) *Tests of Other Raw Materials.*

Other raw materials are sometimes tested for the purpose of ascertaining their composition or their purity. The following are only a few such tests :—

(1) Raw materials analogous to clay are tested by the processes which have just been indicated. For silicious substances, particularly for sand, a washing or elutriation test is used. This is much simpler than with clays, and it is usually only necessary to determine the proportion of earthy materials they can contain. For this purpose, it is sufficient to stir a given weight of sand in a test-glass full of water, allow it to stand ten minutes for each 4 in. depth of

water in the glass, and then to pour off gently the thick liquid, and to repeat this operation until the water remains clear. The sand remaining in the glass is collected, dried, and weighed, the loss in weight indicating the proportion of earthy materials. As the size of the grains of sand plays an important part, it is useful to determine it by means of successive sieves. An examination of the grains with a magnifying glass, or, preferably, a microscope, should also be made, as it will frequently enable the mineralogical nature of the sand or other material to be easily recognized.

When the composition of the sand must be known with accuracy, a chemical analysis alone is capable of revealing the proportion of fluxes which the silicious materials may contain. As the fluxes may be in the form of felspar, the material should be treated by hydrofluoric acid as already described, but instead of treating the solution by baryta, which precipitates all the bases, it is divided into three parts. In the first, the alumina and iron oxide are separated by ammonia, lime by oxalic acid, and magnesia by phosphate of soda. In the second, the iron oxide is treated with permanganate of potash ; and the third is employed for the determination of alkalies (p. 47). Sands are sometimes tested as to their fusibility or refractoriness.

(2) Alkaline fluxes, such as felspar, should be analysed by treating them by hydrofluoric acid, and to determine the alumina, iron oxide, lime, and magnesia according to the usual methods of analysis (p. 47). The insoluble portion is considered to be a mixture of quartz and clay, which can be separated by washing or analysed after fusion with sodium carbonate or heating with hydrofluoric acid.

(3) The analysis of *plaster of Paris* (calcium sulphate) should be preceded by a calcination at 200° C., in order to remove all combined water. The calcined material is then treated for twenty-four hours with a cold solution of ammonium carbonate ; calcium sulphate is thereby decomposed into calcium carbonate and into ammonium sulphate ; the latter is separated by filtering, after which the liquid is warmed and treated with barium chloride, which precipitates the sulphuric acid in the form of barium sulphate, in which form it may be weighed. The filtered liquid is treated with sulphuric acid, any barium sulphate precipitated thereby is filtered off, washed, and thrown away, and the clear liquid is then neutralized with ammonia and the lime is precipitated with ammonium oxalate.

(4) Many other substances are analysed by the ordinary methods of analysis (see p. 46).

CHAPTER IV.

PLASTIC BODIES.

1. Composition and Properties.

The term *body* is used to indicate the material of which a ceramic article is made. It may consist of a single clay or of a complex mixture of several clays and other substances, the proportions of each being carefully adjusted to ensure the body having the desired properties at all stages of manufacture.

Chemical Composition.—Besides the clay and water, which are their essential constituents, most plastic bodies contain four acids (silica, carbonic acid, more rarely sulphuric and phosphoric acids) and six bases (alumina, iron in different degrees of oxidation, lime, magnesia, potash, and soda). Other substances, which are occasionally found in very small quantity, may be regarded as accidental impurities in the raw materials. Omitting the water present, the following figures indicate the proportions in which these different substances can enter into the composition of the bodies.

Silica.—Silica is the principal element of nearly all bodies. They generally contain from 55 to 80 per cent of it, but some refractory silicious wares (such as *silica bricks*) contain as much as 98 per cent, and some refractory aluminous wares (such as *alundum bricks*), on the contrary, contain as little as 2 per cent of silica.

Alumina.—The proportion of alumina in most bodies varies from 10 to 40 per cent. It falls to less than 1 per cent in refractory silica bricks, but sometimes reaches more than 70 per cent in refractory aluminous wares.

Iron Oxide.—Iron is presumed to be in the form of ferric oxide (Fe_2O_3), though ferrous silicates are sometimes present. Its proportion varies from 0 to 8 per cent, this figure being surpassed in certain stonewares, in which it reaches 20 per cent.

Lime, when present, varies between 0 and 10 per cent, but in some marl bricks, terra-cotta, and faiences it can amount to 30 per cent.

Magnesia, which generally accompanies lime, only enters into the composition of bodies in small proportions and, except in rare cases, it does not exceed 4 per cent.

Potash and Soda.—These two bases are often recorded in analyses under the common name of *alkalies ;* their proportion varies from 0 to 5 per cent, but in vitreous porcelain it may reach 17 per cent.

Carbon dioxide is found in bodies in combination with other bases—principally with lime as carbonate. Its proportion may reach 17 per cent, but is usually much lower. When the temperature is sufficiently high most carbonates are decomposed and the carbon dioxide evolved disappears completely during the firing.

Phosphoric acid is only introduced into bodies in the form of phosphate of lime (*bone-ash*) for the manufacture of soft English porcelain, or *china-ware*, which may contain as much as 35 per cent of it.

Sulphuric acid is generally combined with lime as gypsum. Many clays contain small proportions of it, but it is rarely introduced voluntarily into a body, though it is sometimes added to engobes and glazes.

The chemical properties of substances—other than water—which enter into the composition of bodies exert little influence on their preparation, formation and drying, but they play an important part during firing (Chapter VIII). When studying the composition to be given to a piece of pottery in order that it may fulfil the conditions imposed upon it, either of two quite independent points of view may be adopted :—

(1) The manufacture of the ware may be carried on for the purpose of making a profitable use of a given clay—this is frequently the case where bricks, roofing tiles, and coarse pottery are made. The chemical and physical properties of the clay should then be examined and efforts made to ascertain what other materials (if any), and in what proportions, should be added in order that the body may be readily shaped and dried. Firing tests are then made, and from the results obtained—usually after numerous modifications—a useful body is produced from which certain kinds of ware can profitably be made.

(2) A manufacturer may desire to produce a certain class of ware, such as porcelain, earthenware, or stoneware, and it is necessary to find out by what means this result can be best obtained. A chemical analysis of the clay is made, and a series of mixtures is then prepared so as to produce a mixture of the same chemical composition as that of other articles of the kind desired. From this a series of trials is made and fired to ascertain if the physical properties are suitable. From the results obtained the proportions of the mixture, or, if necessary, even the materials used and the mode of firing are altered and re-altered, until a suitable ware is obtained.

These trials generally take a long time on account of the many qualities the pottery must possess, but the use of chemical analysis, unknown to the ancients, enables the trials to be considerably shortened.

The lengthy calculations, which the investigation of the proportions of mixtures of raw materials necessitates in order to obtain a given composition, can often be simplified by making use of the following graphic method, proposed by Bourgerel :—

At the extremities of a horizontal line of any convenient length

two perpendicular lines, each 100 mm. long, are drawn, and each perpendicular line is then marked off in divisions corresponding to the percentage composition of one of the two materials which it is proposed to mix together. This method may be used, as shown in Fig. 3, for mixing a *calcined clay* containing 66 per cent of silica, 30 per cent of alumina, and 4 per cent of iron oxide, and a *felspar* containing 76 per cent of silica, 10 per cent of alumina, and 14 per cent of alkalies; the perpendicular on the right is divided into three parts of 66, 30, and 4 mm. respectively, and that on the left also into three parts of 76, 10, and 14 mm., and lines are drawn joining each of the points so obtained. The base line is then divided into 100 equal parts, and a second line, immediately below it, is simultaneously divided, but in the reverse direction. If a rule rightly graduated is placed vertically on the diagram, the composition of any mixture of this felspar and clay can be read off or, alternatively, if the rule is placed to correspond with any given composition, the proportion of felspar and clay corresponding to it can be read off. If, for example, it is desired to know the composition of a mixture

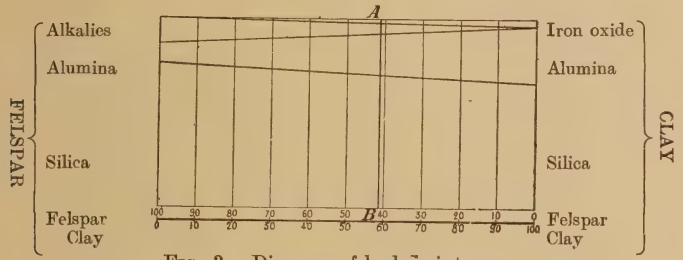


Fig. 3.—Diagram of body mixtures.

41·5 per cent of felspar and 58·5 per cent of clay, the rule is placed, as shown at AB, to correspond to these two figures on the two base lines, and the composition is read off as iron oxide 2·3, alkalies 5·8, alumina 21·7, and silica 70·2 per cent. Conversely, if the rule is placed on the diagram at AB to correspond to this composition, it will be found to indicate a mixture of 41·5 per cent of felspar and 58·5 per cent of clay.

The Forms and Proportions of Water in Bodies.—The water contained in ceramic bodies is in the state of (*a*) hygroscopic water or moisture; (*b*) water of formation; and (*c*) water in combination.

Hygroscopic water is that which a dried body loses on drying at a temperature not exceeding 110° C. and re-absorbs in contact with moist air. Usually the greater part of this water proceeds from the absorption of atmospheric moisture by a clay. The quantity of water so absorbed depends on the temperature and the hygrometric state of the air; it is therefore variable. In very plastic bodies it may reach 10 per cent, and it may fall to less than 2 per cent in non-plastic bodies; the ordinary opening substances—

quartz, sand, calcium carbonate, etc.—are not hygroscopic. Hydrated silica, iron oxide, allophane, collyrite, and some organic substances can increase the proportion of hygroscopic water, sometimes to as much as 20 per cent.

Water of formation is the water added to the body to give it the plasticity and consistency necessary to the mode of shaping adopted ; it evaporates completely when the body is left for a sufficient length of time in a dry atmosphere. This water of formation enters between the particles of the body and should not only fill the spaces between the particles, but should also cover their surface with a thin film of water, thus giving to them a certain mobility and enabling some to be displaced by others. Its action is, therefore, almost wholly mechanical, and in a series of bodies having the same consistency, the amount of water of formation present chiefly depends on the size and shape of the grains, and not on their chemical composition. It unites with the hygroscopic water, and in all studies of the plasticity the effect of this total quantity of water must be noted. Some of it may be present in colloidal gels.

The water in combination (*combined water*) is that which remains in a body which has been dried at 120° C., and only disappears when the body is heated to 450°-600° C. This water forms an integral part of the true clay present, which contains nearly 14 per cent of it. The water combined with aluminium hydrate, halloysite, lenzenite, cimolite, bauxite, talc, magnesite, etc., is also included, but the amount is usually so small that it may be neglected, so that it may generally be assumed that the combined water in a body is proportioned to the true clay present, and in many commercially pure clays the combined water is also proportional to the percentage of alumina. A simple calculation shows that for 100 parts of alumina in the finest particles (true clay) there should be 34·95 per cent, or, in round figures, 35 per cent of water. Any clay or body when dried at 120° C. will still contain from 3 to 13 per cent of combined water according to the true clay present.

Texture.—If plastic ceramic bodies were composed only of pure clay their texture would be represented by imagining grains of extreme fineness and of lamellar form, very close together and entangled one with another, the spaces which separate them being filled with the still smaller particles of water. The addition of other materials to pure clay has the effect of modifying this view, as the particles of most other substances are much coarser than those of clay. Some idea of the texture of a plastic body can be formed by regarding it as a mass composed of grains of varying coarseness, around and between which are much smaller grains of pure clay, the smallest spaces being filled by the extremely small particles of water. If, for the same quantity of clay, the proportion of grains of other materials is constantly increased, a limit is reached where the clay grains are not sufficiently numerous to surround the others, or even to fill the spaces between them ; the clay is then no longer capable of cementing the other grains together, and the cohesion of

the body is destroyed so that it crumbles into dust as soon as the water is evaporated. The largest proportion of foreign substances which may be added to a clay may be ascertained by adding to a clay increasing proportions of the desired substances and noting the mixture, which, when dry, begins to crumble when rubbed lightly between the finger and thumb (see p. 52).

The smaller the grains of non-plastic material, the less spaces will there be between them, and more of them can be added to a given quantity of clay. Hydrated silica, alumina, peroxide of iron, and mica in impalpable powder yield the finest grains, then come the carbonates of lime and magnesia, and finally felspar, sand, and stones. Similarly, the more non-plastic grains there are in a body and the coarser these grains, the less is the amount of water necessary to give the body its definite consistency. Hence, the proportion of water in a body may serve as an indication of the coarseness of the grains of which the body is composed, and also of the proportion of clay present.

In a plastic body there are no "voids," as the spaces between the particles are filled with water, but if a body is in the form of a dry powder, its volume can be diminished by crushing it, and by submitting it to the action of a strong pressure. By these operations the smallest grains are forced into the spaces between the larger, but it is impossible, whatever pressure is exerted, to entirely fill the spaces, about 20 per cent of voids being always left.

The addition of water to bodies obviously diminishes their density, that of bodies containing from 25 to 30 per cent of water varying from 1·6 to 1·7. If, after formation, this water is allowed to evaporate, the resulting dry bodies may have an apparent density varying from 1·82 to 1·73. Thus, a potentially plastic body containing only 5 per cent of hygroscopic water, when subjected to a pressure of 2366 lb. per square inch so as to form tiles half an inch thick, had an apparent density of 1·98. The same body, when mixed with water, made into a plastic paste, and then dried, had densities of 1·74 and 1·79, according as the material had been coarsely or finely ground. On being placed in suspension in water, left to settle slowly, and afterwards dried, it gave a dry body of 1·82 apparent density. In the first case there was 19·2 per cent of space, 29 and 27 per cent in the second, and 25·7 per cent in the third. As dry bodies always contain air, and by the addition of water this air is not always completely eliminated, some of it remains in the form of bubbles when the body is made into a plastic paste.

Consistency.—The consistency of a body when prepared and ready for use depends on the mode of shaping which it is desired to employ ; the following distinctions are made in pottery manufacture :—

(1) *Dry bodies* are those which can only be shaped under great pressure, and even then they always preserve a granular appearance.

(2) *Stiff* or *semi-dry bodies* are those which also need mechanical pressure, although not so great as for dry bodies ; the resulting wares are smooth and feel about as hard as a piece of leather. Hence, they are sometimes described as *leather-hard.*

(3) *Semi-stiff* or *stiff-plastic bodies* are those which can be shaped, though with difficulty, by hand, though they unite badly under the simple pressure of the fingers.

(4) *Plastic bodies* are those which can be shaped and welded easily by hand, and readily preserve any shape given to them. This is regarded as the *normal consistency* for ceramic bodies. It is such that when a mass of plastic body about 2 in. in diameter is squeezed in the hand and then released, it does not adhere to the fingers but, on the contrary, receives a clear impression of the fine lines of the skin. If a body is stiffer than the normal consistency the imprint will not be clear; if the body is too soft it will be "sticky."

(5) *Over-soft bodies* do not lend themselves well to shaping, as the material adheres to the fingers. Articles made of such bodies tend to lose their shape under their own weight.

(6) *Liquid bodies* or *slips* are fluid, and so must be kept in bowls, tanks, or other receptacles.

According to this classification, consistency is estimated by touch, and though this method is very rudimentary, it has been sufficient for all purposes, and it seems probable that it will continue to be so for some time to come. If, however, for more exact experiments, the need of a more accurate measure is felt, a Vicat's needle, 0·04 in. square, and weighing from 1·6 to 3·2 ounces, may be allowed to fall from a height of 4 to 8 in. on to the body; the depth to which the needle penetrates serves as a measure of the consistency.

Another method of measuring consistency really measures the *viscosity* of the material. In this method, the material is placed in a suitable vertical cylinder with a hole of convenient size in its base. Pressure is applied to the material by means of a piston and that required to extrude a pre-arranged quantity of the material is regarded as a measure of its consistency or, strictly, its viscosity. In a modification of the method, the time taken to extrude a pre-arranged column or weight of material under a given pressure is regarded as a measure of the consistency (or viscosity).

The quantity of water which a body must contain to bring it to to any desired degree of consistency depends on the texture; open bodies require much less than plastic ones. It is difficult, on account of the great variations in bodies, to indicate even approximate figures. Hence, the following proportions can only be taken as very rough indications, the smallest number corresponding to very open bodies, and the highest to very plastic ones—

Consistency.	Hygroscopic Water and Water of Formation. Per Cent.
Dry body	7 to 18
Stiff or semi-dry body	10 to 20
Semi-stiff or stiff-plastic body	12 to 25
Plastic body (normal consistency)	15 to 30
Over-soft body	17 to 35
Liquid body	20 to 40 and more.

Plasticity.—The causes of the plasticity of pure clay and the influences which other materials have on this property, have been mentioned in the preceding chapter (pp. 22 and 52). It now remains to examine within what limits it can vary according to the consistency of the body and the pressure to which it is subjected during the shaping of the articles.

If to a potentially plastic, but actually dry, body more and more water is added, the body—which was at first devoid of plasticity—gradually assumed it; it can at first be moulded with difficulty, then more easily, and when the *normal consistency* (p. 60) is reached it may be shaped with the greatest facility. But if still more water is added, the body begins to adhere to the fingers and with a very little more water it is impossible to form it into a definite shape. There exists, therefore, for each body a given proportion of water, at which the shaping is easiest. With less water too considerable an effort must be exercised; with more water the body lacks cohesion, becomes sticky, and is too soft to retain the desired shape.

If the same experiment is repeated with a highly plastic and a feebly plastic body, it will be observed that the most favourable proportion of water for shaping or moulding the more plastic body corresponds to a firmer consistency than that of the leaner clay, and the plastic clay will require more water than the lean one. If the body is so highly plastic that it cannot be given the normal consistency—the range between too little water and too much being very short with such clays—the only way to make it easily workable and to give it a suitable consistency is by "opening" it, i.e. by adding a non-plastic, opening material (p. 37) which simultaneously reduces the plasticity of the body. A very lean body only acquires the desired plasticity by having a very soft consistency, which does not allow it to support itself and to preserve the desired shape. Hence, if such a material is to be shaped by hand or moulded, it must be rendered more plastic—usually by adding a plastic clay or by omitting or removing some of the non-plastic material.

If, instead of the shaping of the ware being done by hand, it is done by mechanical means, in which the body is subjected to a much stronger pressure, less water must be added to the body, in order to obtain the same plasticity, and it will be expedient for it to have a firmer consistency. Pressure, then, plays the same part as water, in relation to the plastic qualities of bodies, and the one can be partially replaced by the other; in other words, if the amount of pressure used is increased, the amount of water used should diminish, and *vice versa*. Thus, if a clay is to be shaped with the minimum of water, i.e. if it is to contain only about 5 per cent of hygroscopic water, the pressure required to mould it may be 1160 lb. per square inch (it would have been impossible to use more water, because the clay would then have adhered to the mould), yet the same clay in the form of a body containing 22·9 per cent water begins to adhere to an iron mould at a pressure of 29 lb. per square

inch, and for a body having 26·4 per cent of water, a pressure of 5·64 ounces might be the maximum.

Great care is necessary when moulding mechanically (see *Pressing*) not to use so moist a material that it adheres to the press-box or mould. If a lean clay is shaped by pressing, the pressure would have to be increased in the same way as, in order to shape it by hand, one is led to give it a softer consistency.

The relations which must exist between the plasticity, the consistency and the pressure corresponding to the mode of shaping the ware, can be summarized as follows :—

(1) Given a body of fixed plasticity, there exists a maximum of pressure and a minimum of consistency between which the body can be shaped satisfactorily. If the body is too plastic, the maximum pressure will be less, and the minimum consistency will be too great to permit shaping by hand, or by a slight pressure as in hand-moulding. If the body is too open, the maximum pressure will become considerable, and the minimum consistency will yield a body which is too fluid to be shaped.

(2) Given a method of shaping corresponding to a fixed pressure and consistency, the plasticity of the body employed can only vary between certain limits. If it is too plastic it will adhere to the mould ; if it is too open its grains will not unite among themselves, and it will be impossible to make a compact mass of them.

It is, therefore, of the highest importance that a careful choice should be made of the method of shaping for a body of a given plasticity, or to produce in a given body the plasticity suitable for a given method of shaping. The solution of these problems is often rendered more difficult by the special qualities which bodies must have in order to give good results in drying and firing, and so that they may, when ready for use, possess the required properties.

2. Preparation of Raw Materials.

(*a*) *Weathering and Crushing.*

The object of breaking up the various raw materials is to bring them in such a condition that they can be easily mixed and converted into a body of suitable consistency and plasticity.

The processes of disintegration vary according to the nature of the materials to be treated, thus :—

(1) " Weathering "—applicable chiefly to clays.

(2) Calcination—sometimes employed for clays and hard rocks, but chiefly for flint.

(3) Mechanical crushing by means of various machines, which may be classified according to their mode of action :—

Concussion	Jaw-crushers Stamps Centrifugal grinders Gyratory crushers Disintegrators	Used for dry clays and for soft and hard non-plastic materials.

Concussion and Crushing	Ball mills	Used for dry clays and for soft and hard non-plastic materials.
Crushing	Edge-runner mills	Used for hard materials, dry and soft clays
	Crushing rolls	
	Pug mills	Soft clays.
	Pan mills (with solid pans)	Used for humid material, soft and hard materials.
Cutting	Cutters	Used for humid and dry clays.
	Granulators	Used for humid clays.

Weathering.—When freshly dug, most clays contain a certain (variable) quantity of water, termed "coursing water," which evaporates when the clay remains sufficiently long in a dry and warm atmosphere. When this evaporation takes place fairly rapidly it causes the lumps of clay to crack and break. The evaporation at first takes place on the surface of the lumps and causes contraction there, but the centre of the mass, being still moist, cannot shrink; the consequence is that the tensions cause the surface to crack, then gradually the lumps crack in the middle, and the mass finally falls into small fragments. This action is much more energetic when the evaporation is rapid, and cannot occur if the drying takes place very slowly.

This natural disaggregation, which is a consequence of the plasticity of clays, is employed in a very efficacious manner for the preparation of compact plastic clays, but it is of little use for open clays which are naturally friable.

In countries where the nature of the climate allows it, clays are laid out in the air and exposed to the sun in pieces of "fist size." In hot weather a few hours are generally sufficient to cause complete breaking up of the lumps. The clay is then collected and placed in sheds ready to be used for the preparation of bodies by dry, pasty, or liquid methods. Where, on the contrary, the climate is frequently moist, the clay is spread in heaps in well-aired sheds, where it slowly breaks up, though less completely than in the preceding case.

When the body must be made into a paste or liquid, a fairly dry clay may be soaked or exposed to the action of the rain. In this case, the surface of the lumps imbibes the water and expands, while the centre, being still dry, does not increase in volume. The result is that the lumps break up. It is convenient to use heaps of clay not more than 3 ft. thick, so that the rain can penetrate them thoroughly. If water under pressure is used, and if holes are bored at short distances from each other, so that the water can penetrate to the centre, the heaps may be made thicker.

In countries where the climate is severe enough for it to freeze regularly every winter, the clay is dug during the warmer season and exposed in heaps, 2-3 ft. thick, to the action of the cold. The water in the clay is transformed into ice, and the resulting increase in volume breaks up the balls, which become completely shattered at the moment of thawing. This action is rendered more powerful

when care has been taken to saturate the clay with water before the frost arrives.

Thus, by making use of solar heat, rain or frost, clays can be broken up in every climate, but it is necessary before adopting a process of "weathering" to know well the average climate of the locality, and the amount of "water of formation" in the clay.

Clay, especially if plastic, should be "weathered" whenever possible, for this treatment has a considerable influence on the preparation of the bodies, and on the quality of the manufactured ware. Mechanical means of crushing may doubtless replace it partially, but are often more costly to work, and experience proves that with the same stock of tools and the same expenditure of power, 6 cub. ft. of body can be prepared with a weathered clay, while only 3 or 4 cub. ft. can be obtained when the same clay is sent direct from its original site to be crushed.

Souring.—In the earlier days of the potter's art, the storage of the clay in sheds for very long periods, often several years, played a considerable part. The use of mechanical crushing machines for the preparation of bodies has often caused the advantages of weathering and souring to be forgotten: in attempts to accomplish more rapid manufacture, grave disappointments have frequently been experienced.

Drying Raw Clay.—Clays may also be disintegrated by artificial drying, this method being employed in damp climates, or when waste heat is available.

The artificial drying of clays is not so simple an operation as would be thought at first sight, because the temperature should not exceed 110° C., and in any case must remain at less than 200° C. if the clay is to retain its plasticity. For small outputs (and even for large ones in the Cornish china-clay industry) the process usually employed consists in placing the clay on iron floors, or on refractory slabs, heated by a system of flues. The thickness of the plates or slabs should be regulated so that the heat transmitted is uniform at all parts of the floor, and that the temperature does not exceed the limit previously noted. The clay is spread in a layer 6 to 9 in. thick and is turned over from time to time in order to hasten the drying and to avoid overheating. A large quantity of heat escapes to the chimney, and the land occupied by the apparatus is considerable, so that it is chiefly employed for small outputs.

For larger outputs more economical dryers are generally used; dryers with shaft furnaces, into which the clay is introduced in the upper part, and passes out below in a dry state, in a continuous manner, being preferred. Fig. 4 represents a stove of this kind, invented by Lecaze. The lumps of clay are placed in an upper chamber, which should be kept filled. From this it falls into the dryer, where it circulates round two rows of furnaces, heated by coke or small coal, so as to subject the clay to a large quantity of air at a moderate temperature. When the clay is dry, it is taken from the lower part of the dryer at regular intervals, the material

removed causing the descent of the upper mass. The air, charged with water-vapour, makes its exit by a series of openings pierced in the arch supporting the upper chamber, and enters two longitudinal flues passing into small chimneys built in the outer walls.

This stove is about 23 ft. high, 6 ft. 6 in. wide, and 13 ft., 23 ft., or 30 ft. long for drying 530, 1060, or 1760 cub. ft. of clay in twenty-four hours. A clay containing 13 per cent of water requires 1·9 to 2·2 lb. of coke per cubic foot in order to dry it to such an extent that it does not contain more than 3 to 5 per cent of water.

Fig. 5 represents a stove constructed by Smidth & Co., which consists essentially of a shaft into which the clay is introduced by

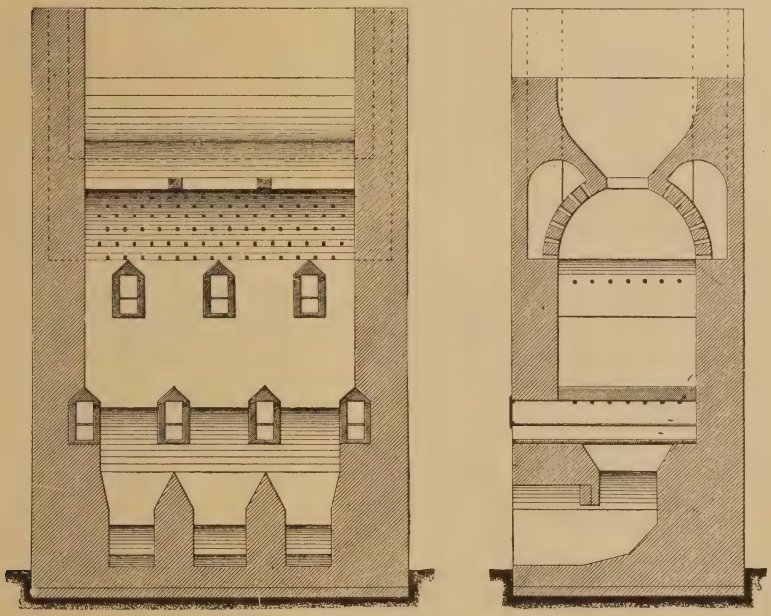


Fig. 4.—Stove for drying clay.

a chute. The lumps of clay descend between the exterior wall of the shaft and a central block of masonry, and when dry are removed through lower openings near the base. The heat is supplied by an outside furnace, the heated air passing through a series of apertures pierced in the top of the central pipe, and after being saturated with water by being in contact with the clay, makes its exit by the chimney : this form of stove is used chiefly for large outputs and for very moist, plastic clays.

Calcination.—Clay is heated to redness or to a still higher temperature in order to reduce the shrinkage, when this is excessive, and also to produce *grog* (p. 40). A similar temperature is also employed to shatter quartz, felspar, and flint. These hard rocks

are heated to a redness, and are then cooled rapidly in water. The expansion and contraction which result from the sudden change in temperature due to the sudden quenching are powerful enough to break the rock into small pieces.

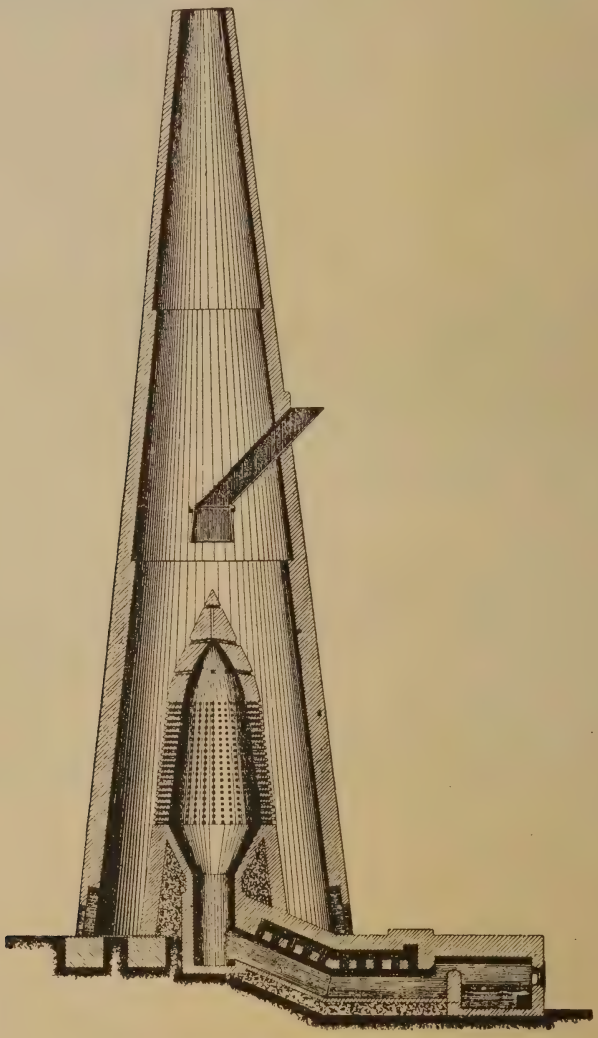


Fig. 5.—Shaft kiln for drying clay.

Shaft kilns are used, similar to those employed for burning lime ; rotary dryers are even more satisfactory.

Fig. 6 represents in section the kind of furnace which is largely

used for flint. It consists of a truncated hearth, surmounted by a chimney, with a grate below and an opening for the removal of the calcined flint. The height of the kiln is 9 to 12 ft., the diameter of the furnace-mouth 35 to 40 in., and that of the widest part, 55 to 63 in. Wood is first placed on the grate, and is covered with alternate layers of stone and fuel in equal proportions, so as to fill the furnace completely. Further supplies of stone and fuel are successively introduced in the furnace in proportion as the mass descends, in consequence of the spaces caused by combustion. As soon as bluish flames are observed on the upper surface of the material, the bars are removed from the grating, the mass falls and forms a sloping heap in the furnace ; the space formed at the upper part is filled up with more stone and fuel and the kiln is definitely in work. When the blue flames again appear at the furnace-mouth it is sufficient to draw, by means of hooks, a certain quantity of the calcined substance from the lower part and to fill up the space produced at the upper part by a new charge of stone and fuel.

In the continuous process of calcination, the proportion of fuel is reduced to about a third of the volume of the stone to be heated. The fuel which gives the best results is wood-charcoal, but because of its high price it is generally replaced by coke.

The burnt flints taken from the lower part of the kiln are either thrown into water or left to cool in the air. In the first case the breaking up is more complete, but the second process must be used when an impure fuel is employed, and it is necessary to remove by hand the slag which adheres to the flint.

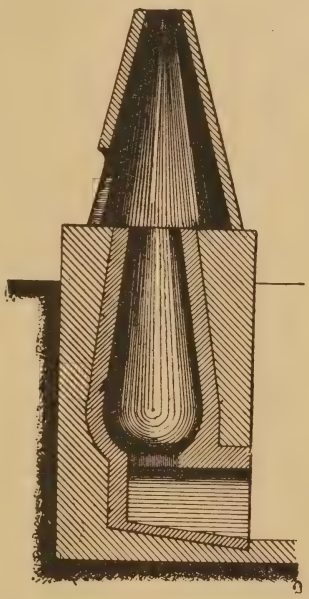


Fig. 6.—Kiln for calcining flint.

Such disaggregation by heat is usually only a preparatory operation which is completed by mechanical concussion, rendered easier by the friability of the calcined stone.

Mechanical crushing is effected by a number of appliances which may differ very greatly from each other. Only the more important ones are mentioned :—

Stamps, which imitate the work of a man with a hammer, were for a long time the only mechanical crushing appliances employed in pottery manufacture. They form grains of unequal size, wear out rapidly, have a low output, and are very noisy. They are no longer employed, except for crushing specially hard materials into

small fragments. The construction of a set of stamps is clearly shown in Fig. 7, which also shows the device whereby each stamp is lifted in turn by the rotation of the shaft.

For small outputs a single stamper may be used and moved by hand, and for still smaller outputs a heavy " head " with a suitable handle may be used like a hammer.

Centrifugal Grinders rotate at great speed, the material to be ground being introduced near the centre and projected by the centrifugal force towards the circumference, receiving on its course numerous blows. These machines may be employed in grinding most raw materials (other than pastes) used in ceramics, though they are not economical when used for very fine grinding. They are not suitable for moist clays, as in this case they have a tendency to choke. They cannot be used to crush materials which must not contain any trace of iron.

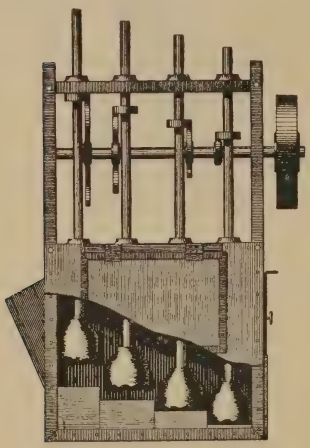


Fig. 7.—Stamp-mill.

Of the many different types of centrifugal grinders the Carr Disintegrator is much used, especially in factories making refractory wares, especially for grinding fired bodies to produce " grog " or " rough stuff." It consists (Fig. 8) of two drums, each carrying two circular " cages " made of steel bars, turning in a contrary direction to each other, the whole being enclosed in a sheet-iron casing. Each drum is fitted at the extremity of a horizontal shaft worked directly by a pulley. The material to be ground is introduced through a hopper at the centre of the machine, where it falls on to the first circle of bars, which strike it, projecting it in one direction until it is struck by the second circle, which turns it in an opposite direction, then by the third turning in the same direction as the first, and then by the fourth rotating in the same direction as the second. The ground material collects at the bottom of the machine, whence it can be removed by a screw, or other suitable arrangement which does not cause clouds of dust. The speed of the machine is regulated according to the degree of fineness of the material desired. Six " cages " are often used instead of four. Disintegrators are made in several sizes, e.g. :—

Diameter of external drum . .	6 ft. 6 in.	5 ft.	3 ft. 3 in.	1 ft. 7 in.
Number of revolutions per minute.	300	350	450	600
Output in lb. per hour . .	44,680	26,800	9,000	340
Horse-power used . . .	36	20	10	1½

Other disintegrators with rotating arms or loosely pivoted " hammers " which beat the material against a grate-like anvil, are

also popular. With these machines the fineness of the product depends upon the size of the openings in the grate. Replacements are more easily made than in the cage form of disintegrators.

Ball-mills consist of a case or drum containing balls of different sizes (Fig. 9) and lined with perforated slabs placed like the steps of a staircase, on which the balls roll and fall. The old types of ball mill were very small, but some modern mills will grind 6 tons or more material per hour. The material is introduced at the centre of the drum, and when crushed by the incessant " hammering " of the balls upon it as the mill rotates, the pieces which are small

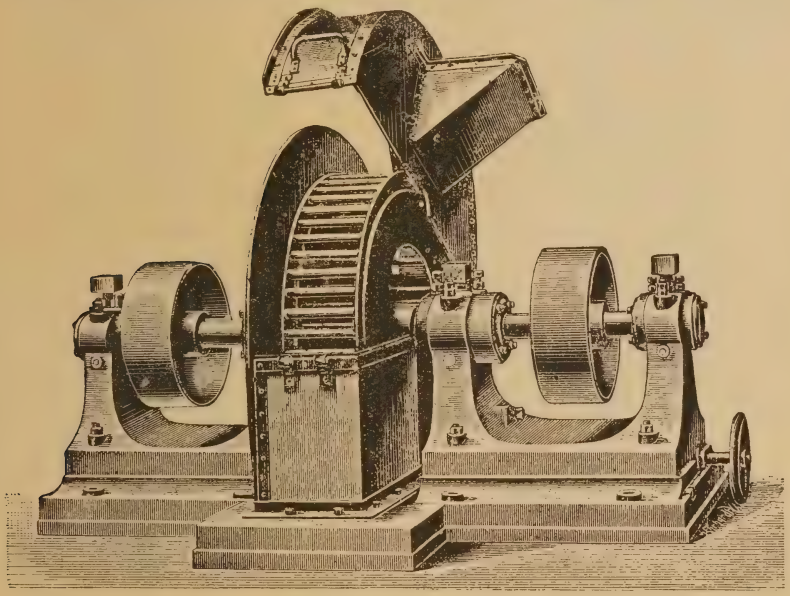


Fig. 8.—Carr's disintegrator.

enough to do so pass out of the mill through the holes in the perforated slabs. In some ball-mills (see " Alsing Cylinder," below), the material remains until it is sufficiently finely ground, when it is taken out and sifted by hand.

The sizes ordinarily used are :—

	ft.	ft.	ft.	ft.
Length	12	10	8	3
Diameter	8	8	6	3
Horse-power required . .	12	8	4	2

Ball-mills are now used in large quantities, and constitute one of the best means of obtaining a fine powder. According to their design, they will grind materials in either the wet or dry state.

An *Alsing Cylinder* consists (Fig. 9) of an iron or steel drum,

lined with silica or with stoneware, into which particles of flint are incorporated to prevent its becoming polished, partially filled with pebbles, being in fact a type of "Ball-mill" (q.v.). A suitable quantity of water and of the material to be ground is fed into the mill, which is then closed and rotated until the grinding and mixing are complete. The door closing the cylinder is then replaced by a sieve, which allows the blunged substance to be run into a tank whilst the pebbles are kept back. Alsing cylinders are constructed to hold a charge of 335 to 3350 lb. of flint; the amount of power required varying from 2 to 12 horse-power. The time required to grind one charge is usually about twenty-four hours, but varies with the material and the fineness required.

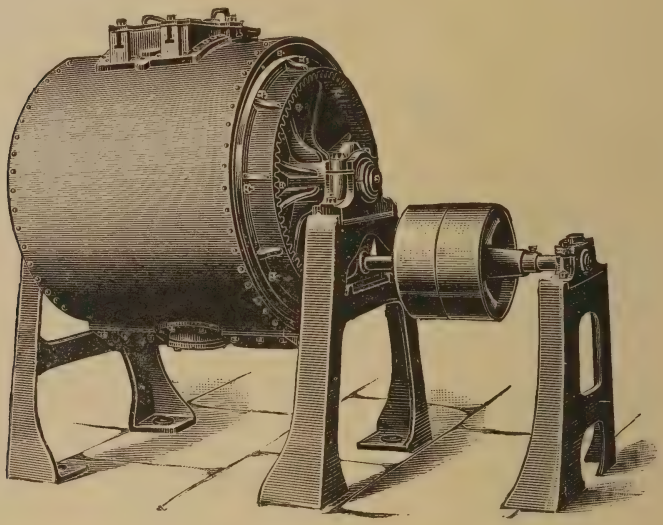


Fig. 9.—Alsing cylinder.

Stone-crushers are used to break hard materials of large dimensions. They are frequently employed as preliminary grinders for lumps which are too large to be placed directly in other grinders, as they require but little power to drive them. Stone-crushers of this type are not adapted to reducing material to pieces of less than half an inch diameter. They consist (Fig. 10) of a fixed jaw, A, and a movable jaw, B, which can oscillate on a shaft, C; the movement is given by an eccentric, D, mounted on a horizontal shaft, E, provided with two parallel fly-wheels and put in motion by a pulley. This eccentric in its slight vertical displacement causes two cranks, F and F, to rock; the first of these is supported by a prop, G, and the second gives a slight oscillation to the jaw, B, causing any material between the jaws, A and B, to be crushed. The reduced material passes through the opening between the bottom of the jaws,

which can be adjusted by moving the block, G. The interior surfaces of the jaws, which are the only parts subjected to a rapid wear and tear, are of hard brass, or steel, and are easily replaced.

Stone-crushers of this type are very popular in several industries, and are manufactured by several firms. They generally run at a speed of 200 to 500 revolutions per minute, and are made in several sizes, viz. :—

Upper opening between jaws in inches	24 by 16	20 by 9	16 by 8	12 by 8	8 by 5	8 by 4
Output in cubic feet per hour . .	352	122	148	106	70	52
Horse-power required	14	10	7	5	2	$1\frac{1}{2}$

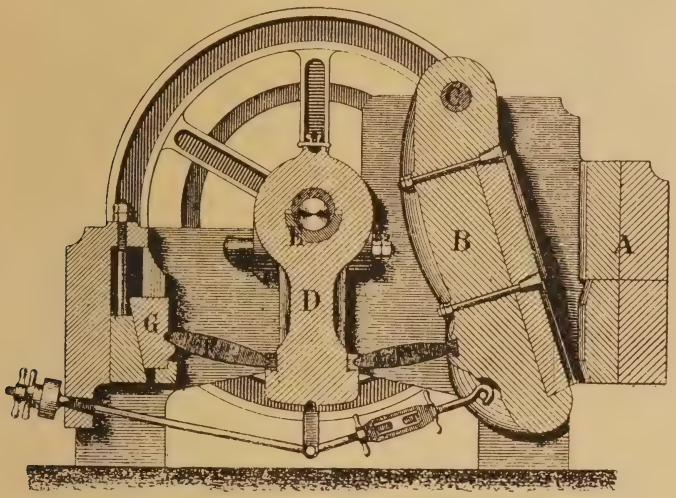


Fig. 10.—Stone-crusher.

Edge-runner mills are frequently used in clay-working, because they can be driven at a low speed, use little power, and wear well. There are two types of edge-runner mills : in one the shaft carrying the rolls rotates about a vertical axis, but the base or pan is fixed (stationary pan or *chaser mill*) ; in the other the base or pan rotates and the shaft is fixed (revolving pan).

The pan may be solid and the ground material is removed by means of scrapers, or a perforated pan may be used and the crushed material collected beneath it. The weight of the rolls may be altered according to the hardness of the materials to be ground. When it is important that the material should be free from all trace of iron, the rolls as well as the pan are made of hard stone ; otherwise they are of chilled iron or steel.

Fig. 11 represents an edge-runner mill of the chaser-mill type, with a fixed perforated pan. The rolls are driven by a toothed wheel placed at the top of a vertical shaft, which is connected to

the horizontal shaft bearing the rolls in such a manner that they may rise in order to pass over any pieces which are too hard to be ground at the first blow. Scrapers of suitable shape bring the un-

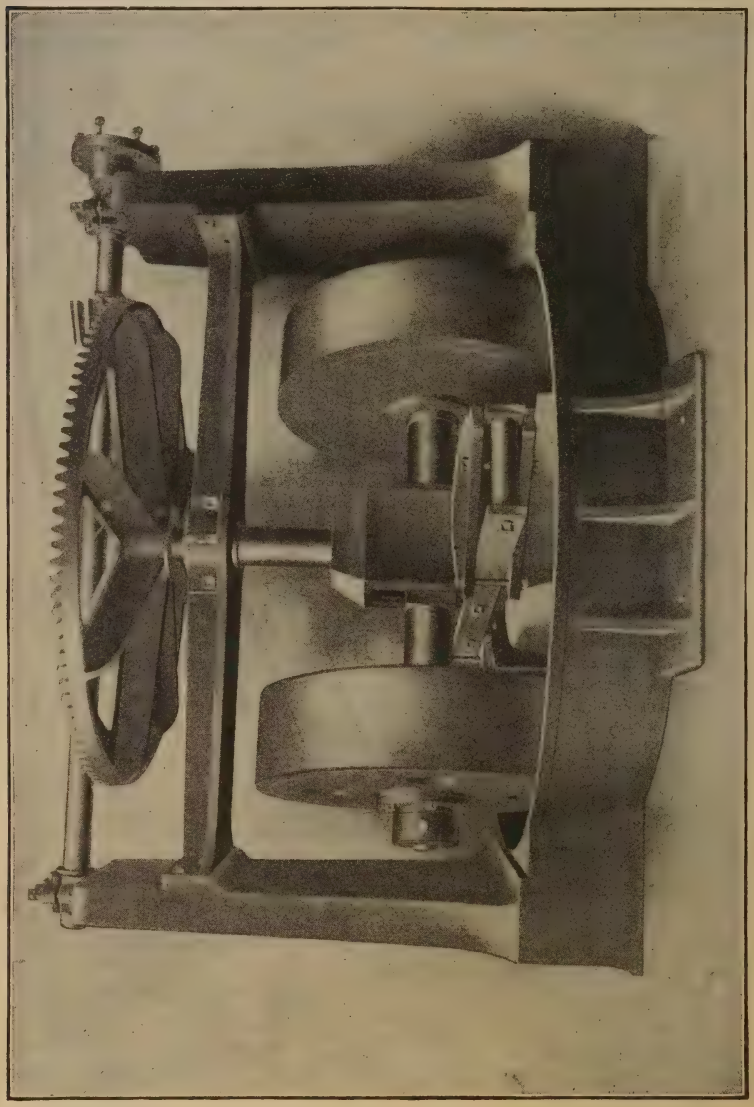


FIG. 11.—Over-driven edge-runner mill.

ground materials under the rolls, and prevent lumps of partially ground material accumulating in heaps. The ground material passes through the openings in the pan and is collected on a tray, or

is removed by an endless screw. The diameter of the pan is usually 9 ft., the weight of the rolls for materials of moderate hardness should be about 1 ton each. The weight of such a machine is about 12 tons, 12-18 horse-power being needed to drive it. In some edge-runner mills the driving wheel is fitted below the pan, as shown in Fig. 12.

The two rolls should have their shafts jointed so that they can be raised independently of each other.

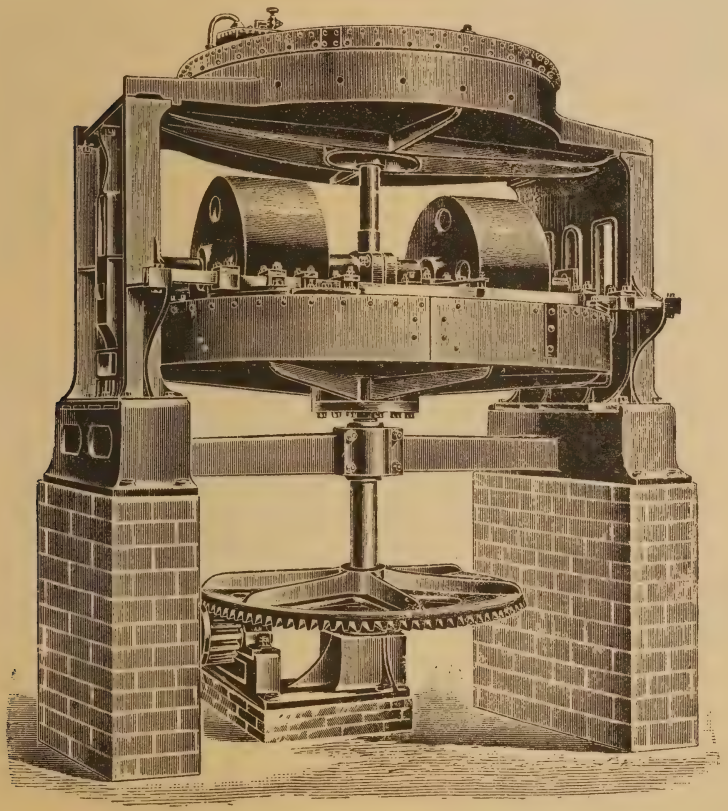


Fig. 12.—Under-driven edge-runner mill.

Mills with revolving pans are largely used in the ceramic industries, particularly for grinding clays for bricks and roofing tiles. They are of two types : (1) Those with perforated pairs, which are used almost wholly for grinding shales, moderate hard clays, and quartzose rocks ; and (2) those with solid pans which do some grinding, but are chiefly used for *mixing*. In mills with revolving perforated pans, such as that shown in Fig. 13, the rolls are caused to rotate by the movement of the material in the pan and indepen-

dently of any direct drive. They can be displaced vertically by variations in the thickness of the material on the pan; this prevents the machine being stopped by overloading and avoids breakages. Fixed scrapers bring the material under the rolls and keep the pan "clean." The output of this apparatus does not differ from that of a fixed pan mill, and, though slightly more complicated in construction, it works admirably and occasions less dust.

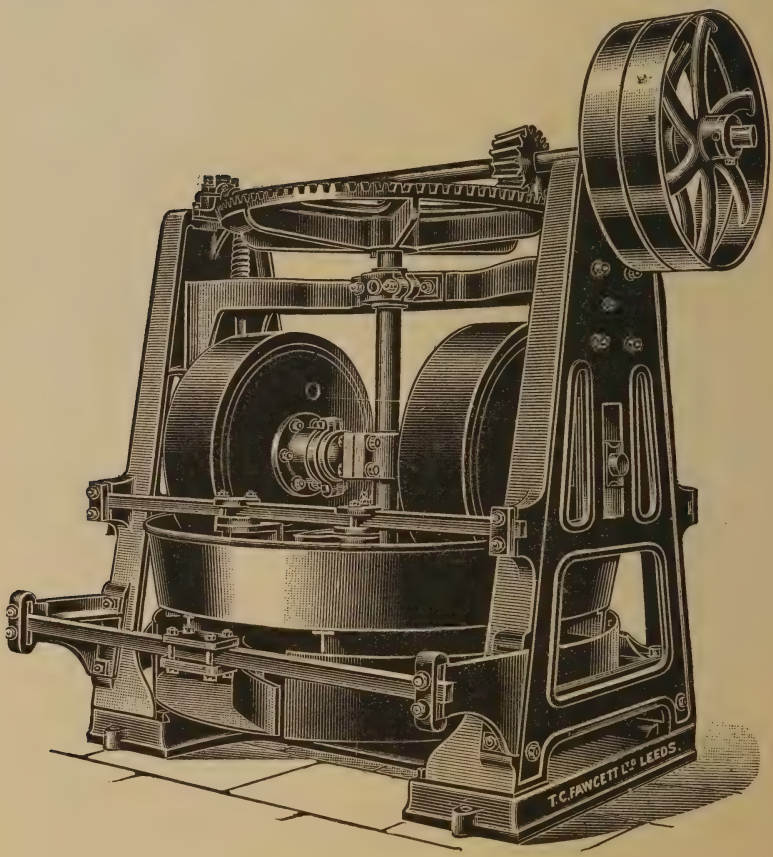


FIG. 13.—Edge-runner mill with revolving pan.

Crushing Rolls.—Although a pair of rolls is well adapted for grinding hard materials, they are only employed in clay-working to break up lumps of clay when "weathering" is not sufficiently powerful for this purpose. These rolls should be of a sufficiently large diameter to enable them to "seize" the lumps. Each roll turns at a different speed, so as to add a rubbing action to that of crushing. The distance between the rolls should be capable of easy

regulation, and some form of safety appliance should be provided to prevent damage to the machine, in case a piece of exceptional hardness (such as a lump of metal) falls between the rolls. Weighted levers, india-rubber pads, or powerful springs can be used for this purpose. Scrapers are arranged beneath the rolls to clean off any clay which may adhere to them.

Crushing rolls are often plain, as Fig. 14, which represents a set of three rolls constructed by W. & W. Wills, Ltd., but sometimes they are fluted, or have projecting parts or teeth (*Kibbler rolls*) in order to seize the clay better.

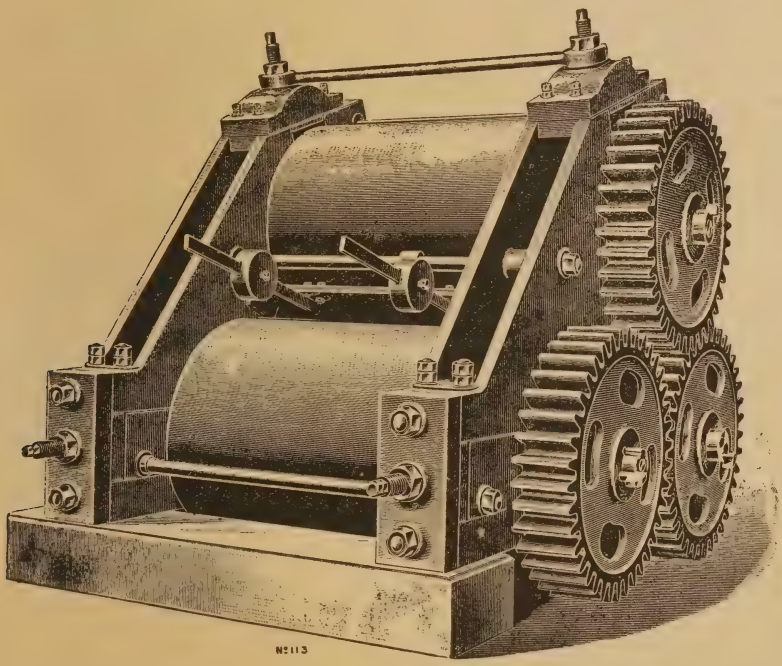


Fig. 14.—Crushing rolls.

For very plastic and tough clays, it is necessary to use several pairs of rolls in succession. The following are particulars of ordinary crushing rolls :—

Diameter of rollers in inches .	16	16	18	20	24	24
Width of rollers . . .	20	24	24	30	30	36

The output varies from 170 to 360 cub. ft. in ten hours for the smaller sizes, and 1400 to 1750 cub. ft. for the larger ones. The driving power required is 2 to 3 horse-power for small rolls, and 8 to 15 horse-power for large ones, but much depends on the hardness of the material to be ground.

Cutters are only employed for plastic clay, or for very friable substances. They are constructed of discs driven at a high speed, knives being attached so as to cut the materials. The chopped material passes out through openings in the discs or between the knives.

When the clay is in the form of large compact and heavy clods, the disc of the cutter is placed vertically, and these clods descend through a chute and press against the disc. With smaller pieces of clay it is better to make the disc turn horizontally, the material to be cut then rests with all its weight on the disc, and a cross-beam prevents it from being carried away by a rotary movement. A machine of this kind, largely used in France, having eight knives, and making 150 revolutions per minute, cuts from 4 to 6 cub. yds. of clay per hour, using a force of 2 horse-power.

Granulators.—The object of granulators is to break materials into small spherical or cubic pieces, or as nearly to these shapes as

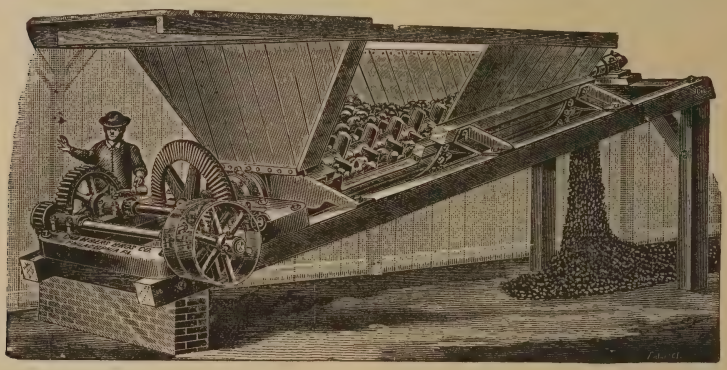


Fig. 15.—Granulator.

possible. For hard stones, the most effective granulator is a stone-crusher (p. 70) with an additional sideways motion of the jaws, which rolls the material about and prevents long flakey pieces from leaving the mill. For shales and indurated clays, a disintegrator of the hammer and grate type (p. 68) may be used, but for some of these materials an open-trough mixer (Fig. 15) is quite satisfactory. The inclination of the machine is varied according to the size of the grains which it is desired to obtain. These machines can granulate 3525 to 7050 cub. ft. of clay per day.

Flint, Felspar, and Stone-mills.—For use in pottery manufacture flint and other forms of silica, felspar, Cornish-stone, and pegmatite must be reduced to an extremely fine powder. For a long time mills with horizontal stones, similar to those used for grinding corn, were used for this purpose, the grind-stones, from 40 to 60 in. in diameter, being arranged one above another with four pairs of grind-stones, but levigating mills (Fig. 36) are now often used, and

consist of a circular vat 4 to 6 ft. wide, the bottom of which is paved with hard stones, and a vertical shaft provided with four horizontal arms, which in rotation impart their motion to blocks of stone. A ring of iron or other suitable material prevents these blocks from rubbing against the walls of the vat. The chief advantage of such grinding mills is that they introduce less iron and grind the material more finely than other types, though they are being gradually replaced by Alsing cylinders.

(*b*) *Purification.*

The processes of purifying raw materials used in ceramics are the following :—

(1) *Sorting*—which is nearly always done by hand, but also by machinery—the coarse impurities being removed when they differ sufficiently in colour, coarseness, or density.

(2) *Sifting*—by which the coarser particles are separated from the finer, as the former remain on the sieve and the latter pass through it.

(3) *Washing*—or separating by mixing with water, the particles which remain longest in suspension being poured off with the water whilst those which settle more rapidly remain behind. The object of washing clays is to eliminate the materials which settle first ; but in the levigation of sands, quartz, and felspar, etc., those which remain in suspension must be removed, and the residue retained. *Elutriation* is a modified form of washing in which the smaller or lighter particles are carried away in suspension in a stream of water whilst the larger or heavier particles sink to the bottom of the elutriating vessel.

(4) *Air-separation*—a process having the same object as washing, but in which water is replaced by a current of air. This process is only applicable to fine, dry materials.

(5) *Magnetic separation* may be used to remove materials which are attracted by a *magnet.*

(6) *Electrical purification* in certain cases enables a part of the pyritic iron to be removed from powdered materials. Some substances which are good electrical conductors can be separated from those which are poor conductors in an electro-static machine. When an impure clay or other material is suspended in water and an electric current is passed through the liquid, the clay and some free silica tends to collect on the anode and the positively charged particles such as ferric oxide tends to collect on the cathode. Water can be separated from clay in suspension in it by this means if a suitable porous diaphragm is used ; this process is known as *electro-osmosis.* In the semi-commercial process known by this name, most of the purification of the clay is effected by the addition of a suitable salt, such as sodium carbonate, when preparing the suspension of the material. The soda causes the particles of clay and some of the finest particles of silica to remain in suspension much larger

than in plain water, and it also causes the coarse particles of sand, etc. (i.e. the impurities) to settle more readily.

(7) *Chemical purification* produces, by the action of certain substances, the elimination of injurious materials or transforms them into inert bodies.

Sorting by hand is much employed for separating the coarse impurities which many raw materials can contain. This operation is generally carried out by women and sometimes by boys. It is employed on a large scale for raw materials of value, such as kaolin and felspar, but only as a preliminary purification to be followed by washing ; for commoner materials, such as ordinary clays, sands, etc., it consists in the elimination of such impurities as stones, pieces of metal, foreign minerals or roots.

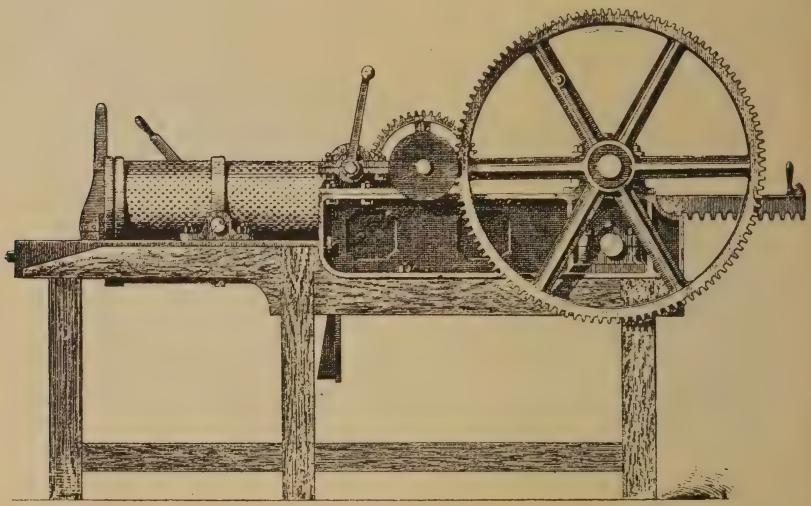


Fig. 16.—Clay separator.

Stones and the coarse hard bodies which some lean clays contain may sometimes be separated mechanically by passing them through a pair of long, conical crushing rolls of small diameter. The clay is readily crushed and passes between the rolls, but the stones, on account of the conicity of the rolls, travel along them and eventually fall over their ends into a chute provided for the purpose. The separation is never complete, some clay being discharged with the stones and some stones being crushed, and so passing between the rolls along with the clay.

Sifting.—In ceramics three kinds of sifting can be distinguished, viz. :—

(1) The sifting of dry, pulverulent materials, which generally follows grinding and does not really purify but merely separates the grains of different sizes, as when dry clays are sifted in order to

remove the coarser particles which they contain. A certain amount of purification may be effected by sifting if the impurities are coarser than the clay. This kind of sifting is carried out on screens, riddles, or sieves of various shapes and sizes.

(2) The sifting of liquid materials, which occurs in the course of purifying by wet grinding, and in the preparation of body slips. Fine sieves or lawns are used for this purpose. The amount of purification effected depends on the impurities consisting almost wholly of much coarser particles than the clay or other materials from which they are to be separated.

(3) The sifting of pasty materials, such as plastic clay. This operation is carried out by compressing the clay into a box or

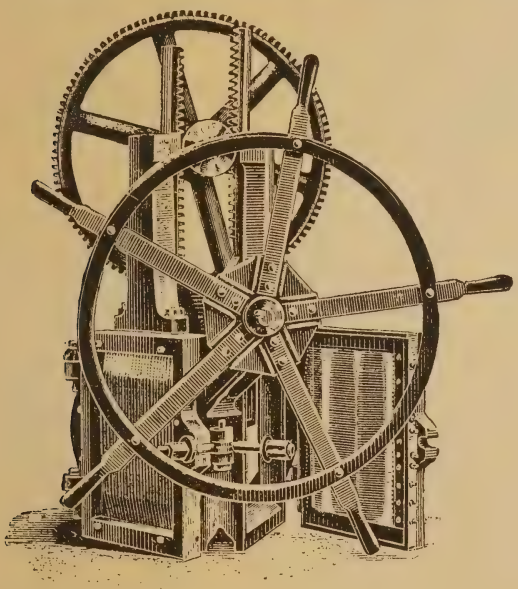


FIG. 17.—Clay separator.

chamber with perforated sides, and by forcing it out through orifices of suitable dimensions, the coarser impurities remaining in the interior. Various forms of apparatus have been constructed on this principle, and differ only in the shape of the chamber and in the mode of applying pressure to the paste. Fig. 16 represents a purifier which consists of a perforated cylinder, and of a mechanism for driving the compressing piston. The perforated cylinder is turned vertically, filled with clay, then lowered to a horizontal position, and by means of a handle acting by two intermediary gear-wheels the workman forces the piston to travel along the cylinder, compelling the clay to make its exit by the holes, while the stones remain in the cylinder. When the piston has reached the end of

its course it is brought back again rapidly by working a second handle fixed on one of the arms of the large wheel. The cylinder is again turned to a vertical position, and the bottom of it is opened so that the stones which have accumulated in it fall out. With this arrangement one man can purify 140 to 275 cub. ft. of clay per day.

Fig. 17 represents a similar purifier in which the compression

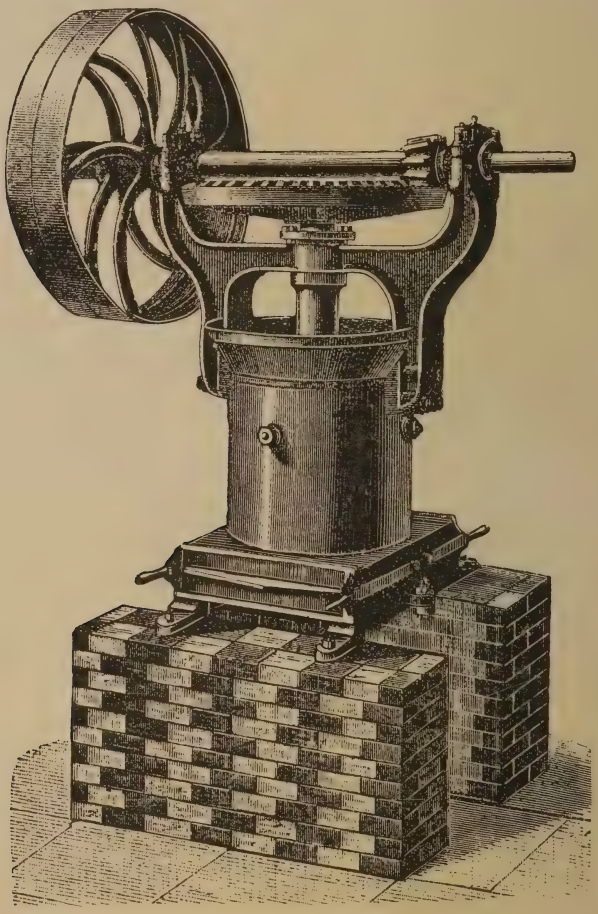


Fig. 18.—Clay separator.

box is triangular and the sieves are parallel plates mounted on hinged doors. A fly-wheel with levers causes a triangular piston to rise or fall. The operation is carried on in the same manner as in the preceding machine.

In order to obtain a larger output, hydraulic power may be used in conjunction with a machine consisting of two cylinders, each

perforated with 1500 to 1800 holes. The cylinders can be turned round one of the uprights of an hydraulic press, one of them being filled or cleaned whilst the other is under pressure. This machine can purify 560 to 700 cub. ft. of clay in ten hours ; the total pressure on the piston is usually about 10 tons.

All the preceding machines act in an intermittent manner, but by using a screw propeller the one shown in Fig. 16 can be made continuous, though it can only be used for fairly soft clays. Fig. 18 represents an arrangement of this kind, in which the clay loaded at the top of the vertical cylinder is compressed towards the lower by

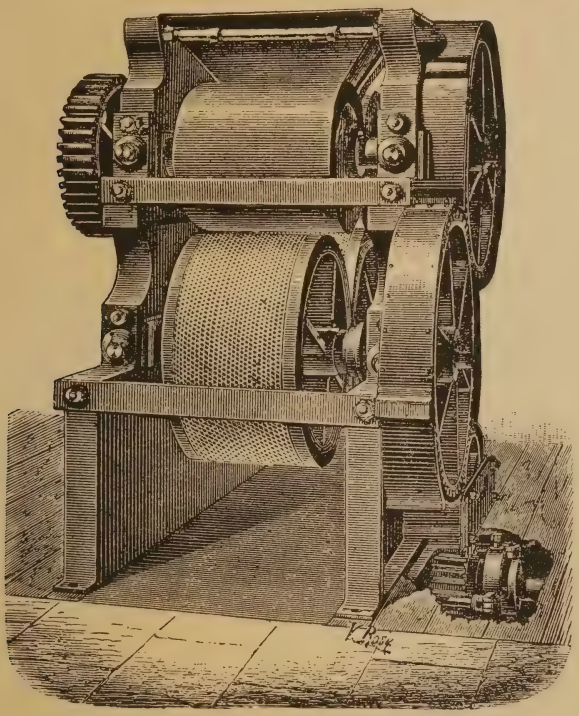


Fig. 18A.—Clay-separating rolls.

spiral knives, and is compelled to pass through the holes perforated in the bottom of the cylinder. Another knife just above the bottom of the cylinder drives the stones towards the sides, whence they may be removed by gradually opening one of the movable panels from time to time.

Purification can also take place in a continuous manner by using a pair of crushing rolls to propel the clay into a box, closed by two movable panels carrying a sieve. From time to time the panels are opened to allow the stones to pass out. A machine of this kind, constructed by the firm of Smidth & Co., is known as the *Elapidator*.

Another arrangement consists of a pair of crushing rolls, the rims of which are perforated or slotted as much as possible. The rolls are provided with springs in such a manner that they exert enough pressure to force the plastic clay through the perforations, but part when a stone comes between them.

Clays which do not occur in a sufficiently soft and plastic state must be prepared by one of the processes mentioned later (see p. 92 *et seq.*).

Washing Clays.—The object of washing is to separate the coarsest and heaviest particles in clay, which settle rapidly, from the finer and lighter ones, which remain longer in suspension in water. Only the coarsest impurities are removed, while those which are in the form of very fine powder, such as fine sand, calcium carbonate, iron oxide, etc., remain at least partially incorporated with the true clay. There is also a partial elimination of soluble salts, but as clays adsorb salts, they cannot be completely washed out.

Washing is generally employed for china clays, and the plastic clays used for the manufacture of porcelain, fine stoneware, faience, and terra-cotta. It is too costly to be employed for the common clays used for the manufacture of architectural terra-cotta bricks and roofing tiles, except in those districts where no sufficiently pure clays are to be found.

The details of the methods of washing vary, for they depend on the nature of the clays, on the degree of purity which it is requisite to obtain, and on the value of the product, but whatever method is employed it necessarily includes three stages :—

(1) *Hydraulicing*, *blunging*, or mixing the clay with water.

(2) Separation of the coarse particles, such as grit and sand.

(3) Placing the clean clay in settling tanks.

These different operations will be dealt with in order.

Hydraulicing.—Open clays, such as china clays, when a large quantity of water may be used, can be treated hydraulically, by being subjected to a jet of water under pressure, which breaks up the clay, carries away the fine parts and leaves the grit behind. For this purpose the clay and water may be run into a vat ; the blunged portion flows away in a continuous manner, the operation only being interrupted when it is necessary to remove the grit accumulated in the vat. For washing china clays out of the decomposed granite with which it is associated, this hydraulic method is much employed in Cornwall ; the rock being attacked directly by powerful jets of water. The stones remain *in situ*, the sand is washed down, and accumulates at the base of the pit, whilst the water which carries away the clay is conducted into large basins.

Clay Blungers.—China clays and other open clays are easily blunged in water, and they can be washed as soon as mined. With plastic clays the operation is more difficult, and it is usually necessary to break them up by one of the processes previously described. Natural or artificial drying is the one most employed, and it is the

most efficacious. When small quantities of clay have to be cleaned, the blunging can be done by hand, by placing a certain quantity of the clay in vats filled with water, and agitating it by means of rakes and paddles moved by one or more workmen.

When all the clay is suitably blunged it is run off into settling tanks through an orifice placed a little above the bottom of the vats, in front of which is a grid or sieve, which retains the grit. The vats are refilled several times, until the deposit of grit has reached the height of the grid ; it must then be removed by a shovel and the vat cleaned.

Besides these special cases, blunging may be effected mechanically, two kinds of mechanical blungers being used : (1) Those with a vertical shaft, which are preferable for open, stony clays ; and

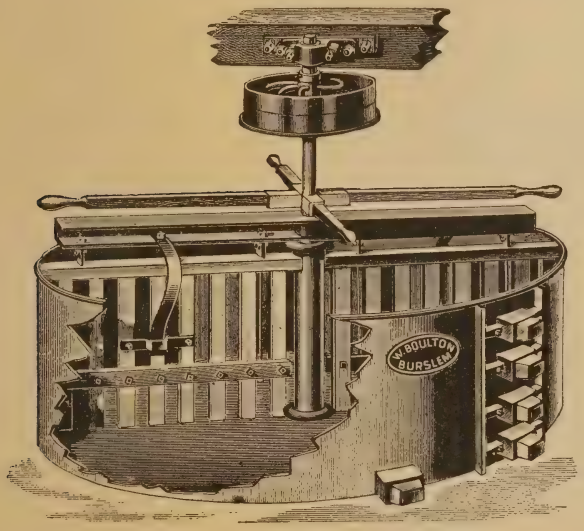


Fig. 19.—Blunger or wash-mill.

(2) those with a horizontal shaft, which are more suitable for blunging plastic clays.

Fig. 19 represents a machine of the former kind for medium outputs. The central vertical shaft carrying two or more wooden arms, from which a corresponding number of harrows is suspended, works in a circular vat, the liquid being agitated by a rotary movement. From time to time, a quantity of clay and a corresponding volume of water are added. The blunged clay may flow out in a continuous or intermittent stream, by opening one of the wooden stoppers which close the outlets placed in the sides of the vats at different heights. The gritty substances accumulate at the lower part, and may, according to their consistency, be removed by hand from time to time from above, or they may be washed out through

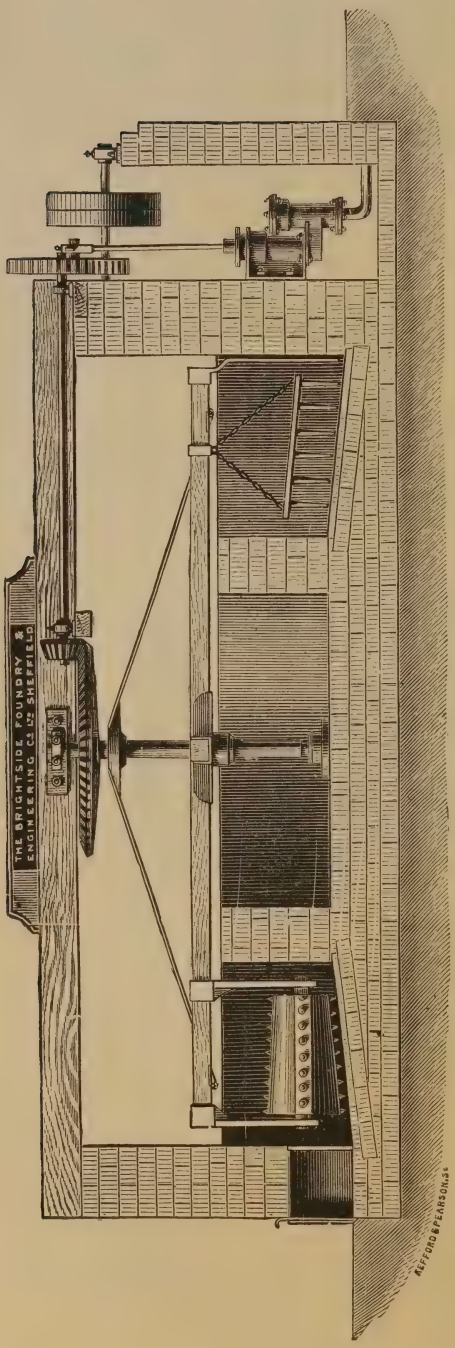


Fig. 20.—Wash-mill.

a lower clearing hole by a stream of water. It frequently happens that when the working of the blunger is stopped for some time, the clay originally in suspension settles and forms with the grit a fairly hard mass, which may break the spikes of the harrows when the mill is started. In this case, the harrows of the blunger should be first raised by hand and gradually lowered as the hard mass is broken up.

In England this machine is usually employed for milling Cornish stone and flint.

For large outputs and particularly for clays which are very stony, the wash-mill, shown in Fig. 20, is used. It consists of a circular trough, in which two or three wooden harrows suspended by chains are rotated, the clay and water are introduced at regular intervals, the slip or slurry flowing out continuously through an orifice provided with a grating placed at a short distance above the bottom of the mill and acting as a dam. The grit accumulates at the bottom of the mill, and in proportion as its thickness increases, the length of the chains is shortened, thus raising the har-

rows ; this flexible suspension has the further advantage of preventing damage on re-starting the mill.

Many attempts have been made to render the working of these blungers and wash-mills continuous, the grit and stones being removed by elevators or screw conveyors, but the advantage which results therefrom is counteracted by the greater repairs needed. It is better to stop and clean out every ten or fifteen days.

The proportion of water used in a blunger is usually two or three times the weight of the clay, but in a wash-mill it may be as much as ten times the weight of the clay, and in hydraulicing still more water is used. The output depends entirely on the tenacity of the clay and on the power used. For medium outputs, horse-driven machines may be used, but for larger outputs a mechanical propeller is necessary. In this case, the quantity of clay washed may reach 1760 and even 2550 cub. ft. in twenty-four hours.

The quantity of water may be greatly reduced and a much cleaner separation of the clay effected if a small proportion of soda

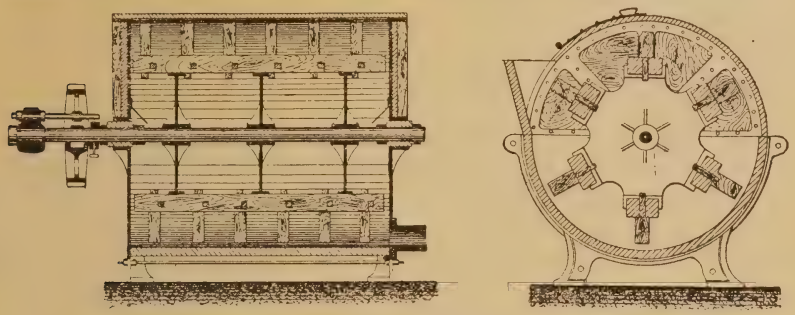


Fig. 21.—Horizontal blunger.

or other suitable electrolyte is added. In most cases as little as 1 lb. of soda per ton of clay will suffice, and an excess must be avoided, as it has an adverse effect (see p. 77).

Blungers with a horizontal shaft consist of a drum, in which is a shaft, provided with several knives. Either the drum may be rotated, the shaft being fixed, or the shaft with the knives revolves inside the fixed drum, or, finally, both may be made to move in opposite directions. The arrangement for the supply of water and clay, as well as the egress of the blunged clay and grit, have roused the ingenuity of constructors. The two following are only given as examples : Fig. 21 represents a blunger with fixed framework in which is a shaft carrying six wooden cross-bars, on each of which are placed six blades. The clay is introduced by a lateral hopper, which is then closed by a cover to prevent the water being thrown out ; the slip is withdrawn through a lower pipe, the clay and sand being carried out by the water, the apparatus only being suitable for clays which are not very stony. The dimensions of these blungers vary from $6\frac{1}{2}$ ft. to $22\frac{1}{2}$ ft. in length, and from 3 to 10 ft. in diameter.

The speed of rotation is from 15 to 30 revolutions per minute, 1 to 30 horse-power being required, and 175 to 875 cub. ft. of clay being washed per day.

In the Schmelzer blunger the clay is fed in a continuous manner by a shovel, at the same time as a small quantity of water, into a kind of pug-mill mounted on a horizontal shaft. The clay is there broken up, and then passes in the form of a pasty substance into a neighbouring box, where it is blunged with a large proportion of water. From there it falls into a sifting framework, which allows the clay and blunged sand to pass; the gritty substances are retained and brought to the extremity of the apparatus, where they fall into a hopper; 180 to 750 cub. ft. of clay may be blunged daily, according to the size of the apparatus and the nature of the clay.

Sand Separators.—In all the preceding machines, the stones and grit in the clay remain in the blunger, or are there separated from the other parts carried away by the washing water; a sieve at the outlet of the apparatus regulates the maximum size of the grains removed at the same time as the clay. Sometimes this treatment is sufficient, and the liquid going to the settling tanks may be used direct, but more often it is necessary to eliminate most of the sand contained in it.

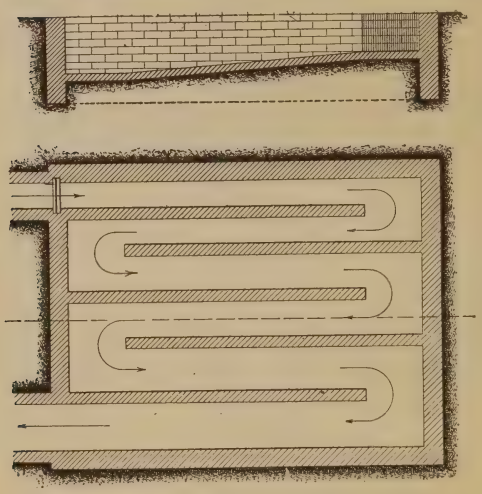


Fig. 22.—Sand separator.

For this purpose it is sufficient to reduce gradually the speed of the liquid according to the degree of purity which it is desired to obtain. For small quantities it is sufficient to allow the liquid from the blunger to flow into a tank, where it is allowed to remain at rest for a suitable length of time. The surplus liquid is then run off into settling tanks, or *washbacks*.

For large outputs the separation is carried on in a continuous manner, by running the liquid from the blunger or wash-mill into conical stonework channels coated with cement, or into wooden trenches. Fig. 22 represents a sand separator of this kind. The sand, which settles at the bottom of the pipes, is removed twice daily with a shovel, or by means of a stream of water.

Fig. 23 shows another type of sand separator in which the slip flows down wooden troughs, leading every 10 ft. or so into casks, at the bottom of which the sand settles, and should be removed by

hand from time to time. The length and slope of these troughs and the number of the casks determine the degree of purity obtainable.

Settling Tanks.—Whatever may be the process of washing, the liquid holding the clay in suspension is finally run into tanks, where all the solid particles can settle. For clays intended for the manufacture of fine wares, several medium-sized settling tanks should be filled successively, but for the manufacture of ordinary ware, tanks of large dimensions may be used, in which the deposit is much less homogeneous, the more sandy particles naturally depositing themselves near the point of entry of the liquid. The size of the tank required may be judged from the fact that even the coarsest particles of clay will only settle about half an inch per minute, and some of the finest particles settle more than ten times as slowly! A large settling tank must usually be left for several weeks, and sometimes for several months before the clay has all settled.

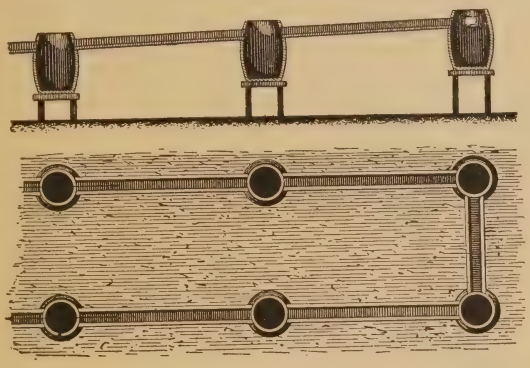


FIG. 23.—Sand separator.

These tanks are provided with lateral outlets, at different heights to allow the clean water to flow away. A pipe with a movable joint may also be used, as shown in Fig. 24. When all the surplus water has been removed, the clayey mass is still too soft to be used; it is necessary to allow it to stiffen by slow evaporation of part of the remaining water, this being the most tiresome part of the operation of washing, for it requires so much time and space. Attempts have been made to shorten it by means of filtering tanks, the base of which is formed by a layer of sand in which drain-pipes are placed. This arrangement acts very well for a time, but the pipes rapidly clog.

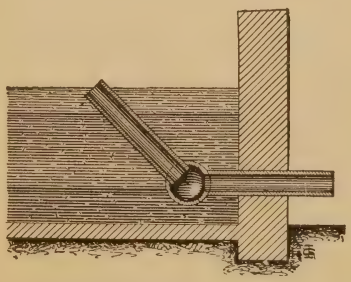


FIG. 24.—Decanting pipe.

The stiffening of small quantities of clay may be hastened by removing it from the tanks and placing it in small heaps to dry in the sun. Filter presses may also be used for the same purpose, and are described in the preparation of bodies by the liquid method

(p. 104). The process of electro-osmosis (p. 77) is sometimes used, but is costly. In Cornwall the china clay from the settling tanks is dried on hot floors with flues beneath. In removing the clay from a settling tank it should be remembered that this clay, which is deposited in successive layers, is not homogeneous, the most sandy parts being at the bottom. It is expedient, therefore, to dig it out vertically in order to have a fairly regular composition.

In all plants for washing clays it is necessary to make use of natural variations of level, or to raise the clay to be washed to the highest point, the settling tanks being at the lowest part. If this cannot be done, an elevating apparatus, such as bucket elevators, plunger pumps, etc., must be used. When the sand is in small proportion and very fine, pumps with simple working pistons and spherical valves can be satisfactorily used.

In **washing sands** and other non-plastic materials, two objects are in view :—

(1) To remove clay and other earthy impurities.

(2) To separate the coarsest particles in order to obtain a fine homogeneous material.

For the first, blungers as just described may be employed. If the materials to be retained are coarse, they remain in the blunger, and are drawn out when the water runs off clear. If, on the contrary, the fine materials are needed they are allowed to flow into settling tanks from which the surplus water is removed later. Sand drains very rapidly, and offers none of the difficulties met with in settling clay. The same process can be arranged to allow the grading or classification of the sand into grains of decreasing sizes.

Air Separation.—By directing a current of air on to pulverized materials they are placed in suspension in the air, as they would be in water. If the speed of the air current is diminished, the coarsest particles settle first, and the finest impalpable powder only falls when the air current is stopped. Separation by air, therefore, acts in the same way as washing, and in certain cases it can economically replace it, though in the ceramic industries this process is rarely employed, except for the purification of some kaolins.

The dry material is first reduced to a fine powder by pulverizers and is placed in a hopper, whence it flows in front of the blast pipe of an air-separator. The air current then enters a pipe of increasing diameter, and ends in one or more large conical chambers, whose dimensions are calculated in such a manner that the parts which it is desired to eliminate settle in the appropriate chamber. The air leaving the last chamber ought to be sifted through canvas or packing, which must be beaten from time to time.

Magnetic Purification.—Iron and magnetic oxide of iron may be removed by utilizing their magnetic properties. The material to be purified should be reduced to a powder and suspended in water, so as to give to the particles to be eliminated a sufficient mobility to enable them to be attracted by the magnets. The material is then allowed to flow through a trough containing magnets, which

are removed from time to time to clean the iron, etc., particles which adhere to them. Plain or permanent magnets may be used, but electro-magnets (Fig. 25) are in every way preferable if provision is made to stop the flow of slip directly the current ceases ; otherwise, the particles of iron, etc., adhering to the magnets may be suddenly released and a larger quantity of slip spoiled.

It is essential that every particle in suspension should come in contact several times with a magnet; in order that every magnetic particle may be removed; to ensure this, the liquid should flow in thin streams past a large number of magnets.

This process of purifying is used in potteries making fine earthenware and porcelain, for removing metallic iron from the body.

Electrical purification may be effected in several ways. *Electrostatic* methods, which depend on the variation in the charges borne by particles of different substances, are of little use in the ceramic industries, as in this respect the impurities too closely resemble the substance from which they are to be separated.

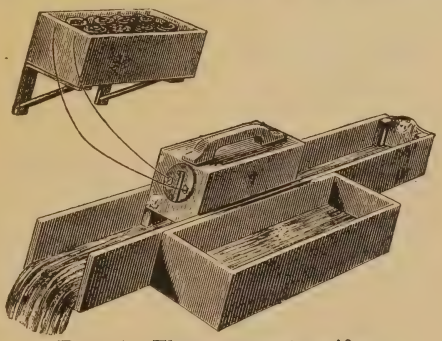


Fig. 25.—Electro-magnet purifier.

Kataphoresis, or the driving of particles in suspension to one or other electrode in an electric circuit, is only applicable to a limited extent, because most of the impurities travel to the same electrode as the clay, iron oxide being the only important impurity which travels to the other electrode, and even its behaviour is irregular (possibly because it is combined with silica).

The removal of water from clay slips by electro-osmosis has been mentioned on page 77. Though used in Germany on a commercial scale, it has not been widely adopted elsewhere, chiefly because it is regarded as being more costly than other methods of de-watering clay. The Schwerin electro-osmosis machine consists of a trough containing a positively charged horizontal roller rotating above a negatively-charged wire-netting. The clay is deposited on the roller and is removed by a scraper. One ton of clay containing 12 to 20 per cent of water is separated from a suspension by the expenditure of about 40 kilowatt-hours of electrical energy.

Chemical Purification.—It is only in very rare and quite special cases that raw materials used in ceramics can be purified chemically, in the sense that impurities may be removed in solution or by precipitation as the result of the addition of a chemical reagent. Some purification of clays and other materials occurs in nature as the result of chemical actions due to weathering, but these are of too complex a character to be repeated artificially, at any rate on a

scale which is commercially profitable. A very remarkable method of purification by the addition of sodium carbonate or of other suitable electrolytes must, however, be mentioned.

It has been found that the addition of a very small proportion of sodium carbonate to the water used for bringing a clay into suspension will enable the non-plastic materials present to settle much more rapidly than when plain water is used. The precise cause of this action is unknown ; it appears to be related to the colloidal properties of the clay. If a suitable amount of soda is used—an excess being carefully avoided—the clay can be suspended in a much smaller quantity of water than would otherwise be the case. If an insufficient amount of water is used, however, some non-plastic matter will remain in suspension with the clay (see *Casting*, p. 141).

The *souring* or *mellowing* of plastic clay pastes also appears, at least in part, to be the result of chemical reactions, though they are of an obscure nature. A chemical reaction which has beneficial results, though it can scarcely be regarded as a means of purification, is the use of barium salts to prevent the formation of an efflorescent or *scum* on articles made of a clay or body containing sodium sulphate or other soluble sulphates. Either barium chloride or barium carbonate may be used, the latter being preferable as an excess of the chloride may itself form a scum. The sulphate and barium salt undergo a double decomposition :—

$$Na_2SO_4 + BaCl_2 = 2NaCl + BaSO_4$$

or

$$Na_2SO_4 + BaCO_3 = Na_2CO_3 + BaSO_4.$$

The barium carbonate must be in a very fine powder in order that chemical action may be produced completely without it being necessary to add too great an excess of the reagent.

The proportion of barium carbonate to be added is easily calculated when the amount of sulphate in a clay is known, but it is expedient to use twice the quantity theoretically necessary. Witherite (a native barium carbonate) may be used, but a chemically prepared barium carbonate is in many ways superior to it.

The use of dilute hydrochloric acid to remove the calcium carbonate contained in some clays (by the formation of calcium chloride, which is removed by washing) has never been employed on a large scale, as the acid affects the plasticity of the clay. Washing with acidulated water will also eliminate some of the iron oxide, but as such treatment spoils the clay, rendering it unworkable, it cannot be employed except for some non-plastic materials.

3. Preparation of Bodies.

After the raw materials have been broken into small pieces and purified, so far as purification is necessary, the next stage in the manufacture consists in mixing them in suitable proportions in such

a manner as to produce a body having the desired homogeneity, composition, and consistency. The preparation of bodies includes three series of operations, which may be carried out either successively or simultaneously :—

(1) Measuring the raw materials, to ensure the desired composition.

(2) Mixing the materials to render the body homogeneous.

(3) Further operations to give the body a suitable consistency.

Bodies are prepared by :—

(*a*) Plastic methods, in which the materials are mixed to form a plastic body of the desired consistency. A *soft body* is distinguished from a *stiff body* by its consistency.

(*b*) Dry methods, in which the materials are mixed in the form of a dry or semi-dry powder, being moistened, later, if necessary, in order to obtain the desired consistency.

(*c*) Liquid methods, in which the materials are blunged and mixed with water so as to form a *slip* (p. 60), which is afterwards partially dried in order to give the body the necessary consistency ; or the body may be used in the form of a slip as in *casting*.

Plastic methods are usually the least costly ; they are preferred in the manufacture of bricks, roofing tiles, terra-cotta ware, made of refractory materials, all kinds of earthenware, including faience, and stoneware, especially when clays are used which have, naturally, the desired composition. They are not suitable where the proportions of the materials must be accurate within narrow limits, and become laborious if it is desired to obtain perfect uniformity of composition.

Dry methods, on the contrary, lend themselves to an exact apportionment ; the materials may easily be mixed and the texture of the body may be coarse or fine at will. They are often employed in the manufacture of refractory articles, some architectural terra-cotta, fine earthenware (faience), and stoneware, and some porcelain. The only drawback is that only those materials can be used which are sufficiently dry to be crushed. A liquid method should be used when a very fine texture and a very intimate mixture are desired, though it is more costly and more complicated than the others. This method is used in the manufacture of porcelain ware, some fine earthenware (faience), and some fine stoneware.

(*a*) *Preparation by Plastic Methods.*

In preparing a ceramic body by a plastic method there are usually two distinct operations : (*a*) The measurement of the raw materials and the water ; and (*b*) the mixing of the materials. According to the amount of moisture in the raw materials they are treated in one of three ways :—

(1) Raw materials which contain a suitable proportion of moisture are placed directly in the mixing machine in the desired quantities, as three barrowfuls of plastic clay, one of open clay, and one of sand.

(2) Raw materials which are too dry to make plastic bodies must have water added to them.

It is by no means easy to produce a homogeneous mixture of clay and water, especially if the clay is pasty.

An open, lean clay, which easily absorbs water, may be placed on the ground, or better, on a board, in heaps 3 ft. to 4 ft. 6 in. high, formed of horizontal layers of various raw materials, the thickness of each layer corresponding to its proportion in the body, as 15 in. of plastic clay, 5 in. open clay, 5 in. sand, then again 15 in. plastic clay, and so on. During the formation of the heaps they are sprinkled with water from a hose or watering-pot, and the whole is left for at least twenty-four hours and as much longer as possible, so that the moisture may distribute itself evenly throughout the whole mass ; the heaps are then cut vertically and the pieces brought to the mixing machine.

Dense clay, which absorbs water with difficulty, is similarly treated, except that the successive layers are placed in pits and water is added until the material is covered. Any excess of water may be removed by opening a bung-hole provided in the lower part of the pits. The pits are usually 3 ft. 3 in. to 6 ft. deep, and have a capacity of 8 to 35 cub. yds. ; they are dug out of the ground and lined with cement or bricks. The mass should remain sufficiently long in the pits for the clay to be completely broken up and thoroughly soaked. The usual time is twenty-four to seventy-two hours. Some clays are so impervious that this process is quite useless ; they must usually be dried (if necessary by artificial heating) before being soaked in pits.

Some plastic clays can best be mixed with water in an edge-runner mill followed by the addition of a further quantity of water when the clay is being passed through an open trough mixer and pug-mill.

When two plastic clays cannot be mixed together satisfactorily in the plastic state they may be dried, reduced to powder, mixed, and then re-converted into the plastic state, or they may be separately blunged with water, mixed, and the excess of water then removed as described later.

(3) Raw materials which are too moist to be used (as in wet weather, or when clay has been washed) should be : (*a*) mixed with dry powdered clay or a non-plastic material, and then treated as in (1) or (2)—sometimes the dry clay may be replaced by broken products which have been warped or cracked during the drying ; (*b*) partially dried by artificial heat ; or (*c*) filter-pressed as described later.

The **homogenization** of the body comprises two operations : *crushing* or *grinding*, by which the lumps of clay, pebbles, and stones are crushed ; and *pugging*, the object of which is to mix intimately all the substances which compose the body. These two operations ought not to be considered as quite distinct, for crushing or grinding causes a certain amount of mixing and pug-mills will also break up lumps in the clay. When the body contains neither

pebbles nor other stones, grinding is unnecessary and pugging may be sufficient, but the latter is an indispensable operation for the obtaining of a body of uniform composition.

Crushing or *grinding* can only be done by mechanically-driven mills, as devices worked by hand are not efficacious.

Crushing rolls usually consist of two hard cast-iron cylinders, driven by two cog-wheels, the teeth of which are arranged so as to be adjusted for wear and tear (Figs. 14 and 26). They generally rotate at different speeds so as to break up the clods of clay efficiently, and are provided with scrapers in order to detach those which adhere.

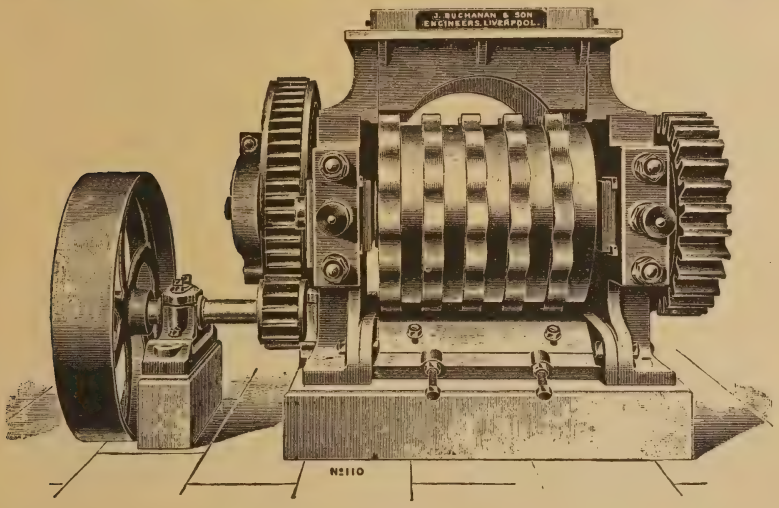


FIG. 26.—Kibbler crushing rolls.

The outputs and power required are shown in the following table :—

Diameter. Inches.	Length. Inches.	Output in Cubic Yards per Hour.	Horse-power.
11	11	1	2 to 2½
15	15	2 to 3	3 to 4
19	19	4 to 5	5 to 6
23	23	7 to 8	8 to 9

When the clods of clay are too large or the stones too numerous they must be passed through two or three pairs of rollers in turn, the upper rollers being set apart, while the lower ones are put as close together as is suitable to obtain the desired degree of fineness of the product. The second and third pairs of rolls rotate more rapidly than the first, in order to allow them to deal with the same quantity of body.

The amount of mixing produced by the rolls may be increased by fluting them, or by making them conical in form, the smaller

diameter of one being placed in front of the larger diameter of the other. Scrapers remove any material which may accumulate.

Pugging was formerly done by treading the clay with feet on floors, or in shallow pits, or by means of horses or oxen which walk round and round a circular track. Treading is still carried on in the same manner in making crucibles for steel melting, but for other articles vertical or horizontal pug-mills are now almost exclusively used.

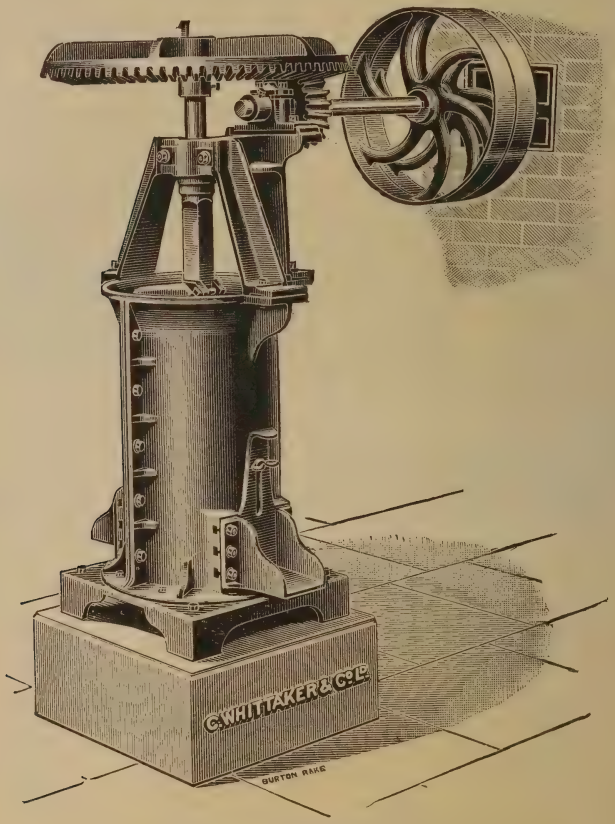


FIG. 27.—Vertical pug-mill.

Very small quantities of materials may be moistened on the floor or on a board. After having added the necessary amount of water, the body is kneaded, left standing for a day or two, and then kneaded again. For larger quantities this primitive process has now been replaced by pugging, all the pug-mills described being suitable.

Vertical pug-mills consist of a cylinder closed at the base, in which rotates a vertical shaft carrying knives at different heights. The

body is introduced at the top of the mill, and passes out through a lower opening, the size of which can be regulated at will. Fig. 27 represents a pug-mill of this kind. Sometimes pug-mills are under-driven, but, unless under special circumstances, this arrangement is not to be recommended. For a small output, the driving-power can be replaced by manual labour or a horse, in which case the driving shaft is fixed directly on to the shaft of the pug-mill.

The material descends by its own weight, but in order to increase the output the knives should be arranged in spiral lines, so as to compress the clay towards the base. Vertical knives are also provided to divide the mass. At the bottom of the pug-mill a double knife is fitted to drive the pugged body towards the outlet.

Pug-mills are constructed with a diameter varying from 10 to 40 in., and a height from 40 to 80 in., the shaft making from 8 to

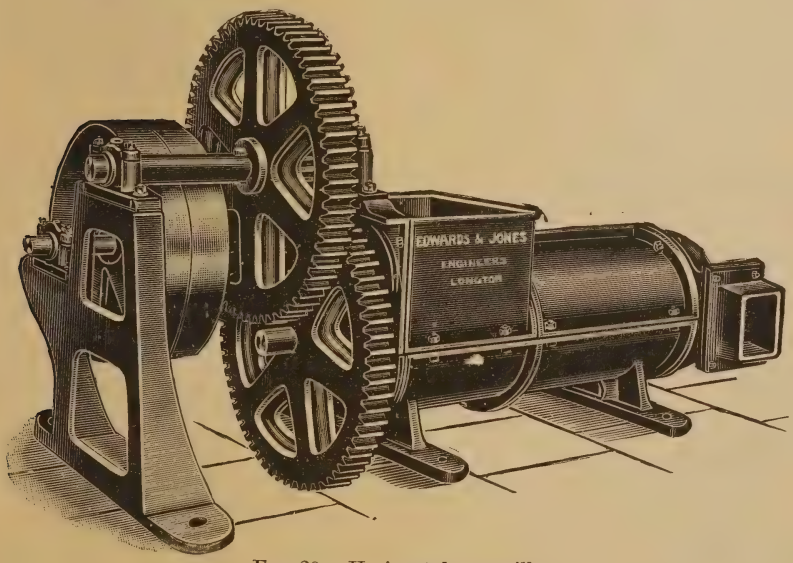


Fig. 28.—Horizontal pug-mill.

12 revolutions per minute; their output depends entirely on the degree of plasticity and the consistency of the body; for lean clays having a consistency corresponding to that of clay used for hand-moulding one horse can pug about $1\frac{1}{4}$ cub. yd. per hour; for a highly plastic clay the same result can only be obtained with two or three horses. Vertical pug-mills worked by mechanical power are of the dimensions given below :—

Diameter. Inches.	Length. Inches.	Output in Cubic Yards per Hour.	Horse-power.
20	40	0·7 to 1·2	1 to $2\frac{1}{2}$
28	59	1·5 to 2·5	2 to 4
36	78	2·5 to 4·0	3 to 6

When it is desired to obtain stiff yet plastic bodies, it is preferable to use a horizontal pug-mill (Fig. 28) consisting of a horizontal barrel of cast iron in the centre of which rotates a shaft with knives

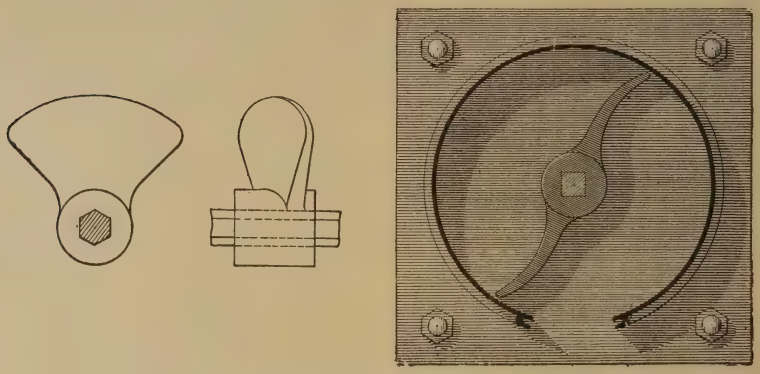


Fig. 29.—Pug-mill knives.

arranged in a spiral. The material enters at one end and passes out at the other.

The knives (Fig. 29) being of cast iron, or with a shank of cast iron and adjustable blades of iron, or steel, are helicoid in shape, corresponding to $\frac{1}{8}$, $\frac{1}{4}$, or $\frac{1}{2}$ spiral. Usually the width of the knives increases from the inlet of the pug-mill to the outlet. Contrary to what takes place in vertical pug-mills, the body, especially if it is rather plastic, tends to turn with the blades, and to prevent this movement, which would stop nearly all the mixing, some "counter knives" are fixed in the cylinder (Fig. 30).

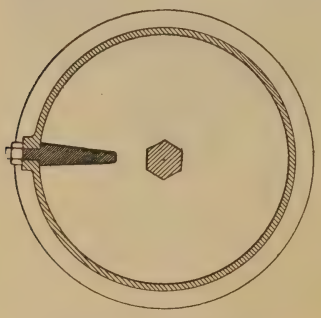


Fig. 30.—Counter knife.

Horizontal pug-mills are constructed with diameters varying from 16 to 28 in., lengths from 36 to 98 in.; the speed of rotation being 10 to 25 revolutions per minute. The output is approximately as follows :—

Diameter. Inches.	Length. Inches.	Output in Cubic Yards per Hour.	Horse-power.
17	78	2 to 3	3 to 5
23	78	4 to 6	5 to 8

The power required varies greatly with the stiffness and other properties of the paste.

Trough Mixers.—Horizontal pug-mills can also be constructed with two rotary shafts bearing knives turning in opposite directions,

according to the arrangement shown in Figs. 31 and 32; such a machine is usually termed a *trough mixer*. It is generally of sheet iron, and is open above. The material is fed in at one end of the machine, and passes out by a lower opening at the other end. The shafts are driven at one end by fixed gearing, and are supported by ring bearings. The knives are helicoid in shape, corresponding to $\frac{1}{8}$ or $\frac{1}{4}$ spiral. They work in sets of four, six, or eight blades. Fig. 31 shows two sets of blades; in each set four blades make one complete turn. These mixers are constructed with a width of 18 to 48 in., and a length of 50 to 148 in. The speed of rotation is 12 to 15 revolutions per minute, and the output is 70 to 1000 cub. ft. per hour, for an expenditure of 3 to 15 horse-power. They are good machines, having less wear and tear than closed horizontal pug-mills with a shaft, but furnish a body of less density.

To moisten the clay in a pugmill or trough-mixer it is usually sufficient to fix a pipe for the supply of the water, and to regulate the flow by a tap. The open trough-mixer is, in this case, especially

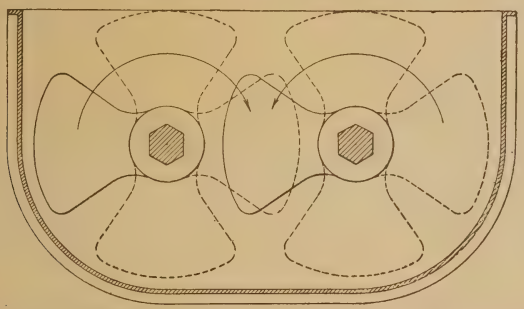


Fig. 31.—Diagram showing blades of double horizontal mixer.

useful, as the water-tap may be connected to a pipe laid parallel to the shaft, pierced with a fairly large number of orifices, by means of which the water can be distributed uniformly over the clay.

Sometimes warm water or even steam is used, but it is then necessary to proceed at once with the shaping, as the body dries rapidly.

Souring.—Whatever may be the type of pug-mill or trough-mixer adopted, it is well, before using the pugged body, to let it remain in heaps covered over with damp cloths for at least twenty-four hours to "sour." This allows the grains of clay to become more completely combined with the water than they could have done during their rather short passage through the pug-mill. The result is an increased plasticity of the body, which often facilitates shaping the ware. Only in the case of the manufacture of very common wares, or when the actual moulding is preceded by rough shaping, can the body be used as soon as it has left the pug-mill. After souring, the body should be re-pugged through a slow-moving pug so as to compact it thoroughly.

Rolling and Pugging Combined.—Rolls and pug-mills, such as have just been described, may be placed close to each other, and the material made to pass from one to the other by means of an endless band or by gravity. An arrangement frequently used consists in placing the rollers above the pug-mill. Fig. 33 represents a com-

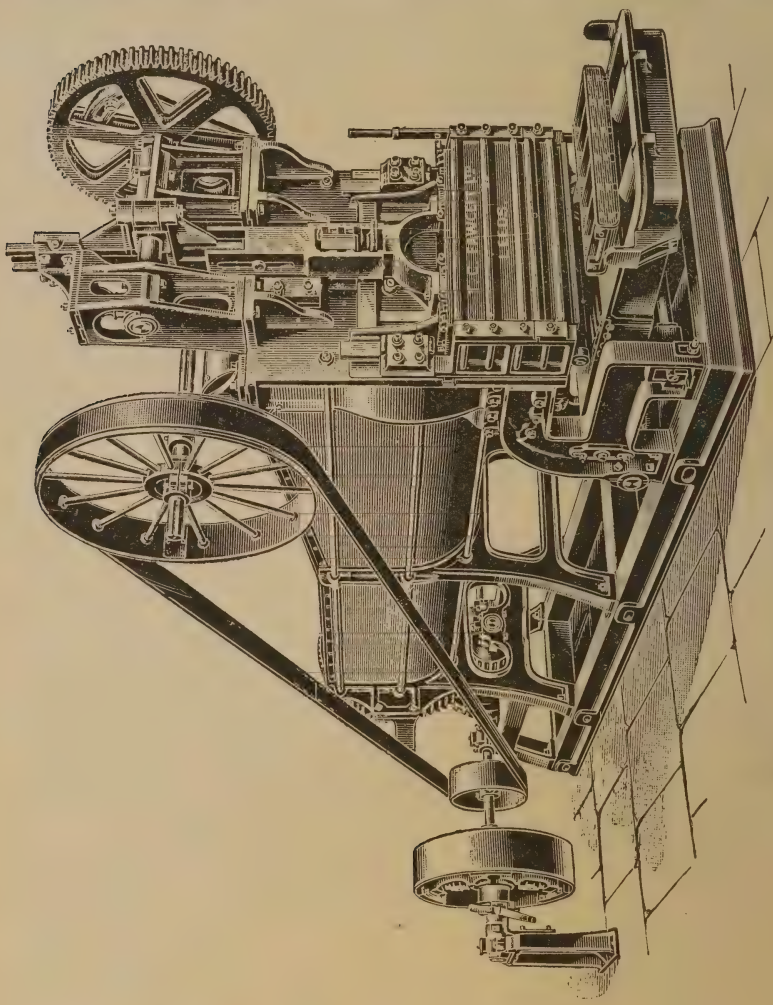


Fig. 32.—Brickmaking machine with double-shafted mixer.

bination of a pair of rollers with a horizontal pug-mill. Various other combinations of rolls, trough-mixers, and pug-mills are largely used in the manufacture of bricks.

Preparation of Stiff-plastic Body.—The machines just described are most suitable for the manufacture of a soft body, but when a

stiffer one—technically known as a stiff-plastic body—is desired, some modifications are necessary. In the latter case, the mixing cannot be effected in pits, which would yield too soft a body, but

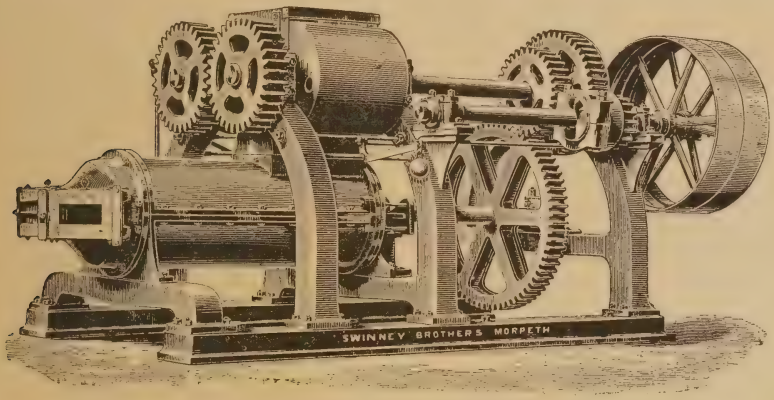


FIG. 33.—Combined rolls and pug-mill.

must be done in heaps, unless the raw materials have, naturally, the required proportion of moisture.

Uniformity is effected by rolling and pugging as in the preparation of soft bodies, but the machines should be more rigid, and a

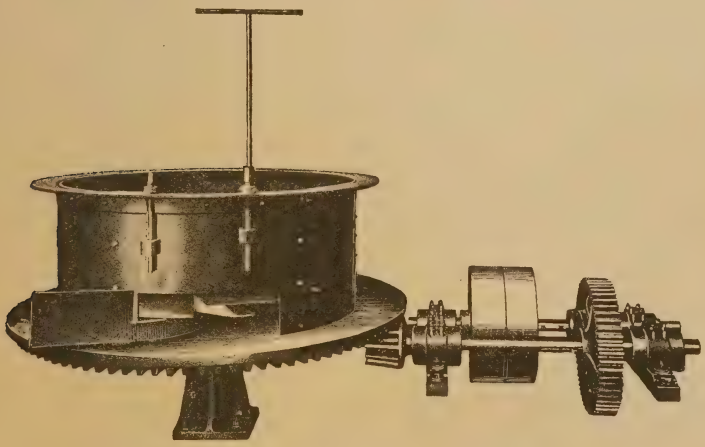


FIG. 34.—Rampach's "Automat" feeder.

greater driving power is necessary. The use of rolls is almost indispensable in the preparation of stiff-plastic bodies, for their great stiffness prevents ordinary pug-mills from being sufficiently efficacious, and vertical pug-mills of a small height (about 40 in.) are usually employed, as horizontal pug-mills would require too much

power. During recent years, however, very powerful, horizontal pug-mills have been used very satisfactorily for producing bricks from a stiff-plastic paste which is cut up by means of wires—hence the name "wire-cut process" for bricks.

In the preparation of very stiff bodies it is not desirable to allow the pastes to remain standing after they leave the pug-mill before their formation.

The chief objects of using machinery to produce stiff-plastic pastes are: (*a*) to reduce the amount of moisture which has to be dried out of the articles made from the clay; (*b*) to reduce the cost of manufacture by making the freshly made articles easier to handle as well as much cheaper to dry; and (*c*) to enable clays, etc., to be used which are not sufficiently plastic to produce the ordinary soft plastic pastes.

When stiff plastic materials are to be mixed in definite proportions the use of an "Automat" feeder (Fig. 34) is advantageous.

(*b*) *Preparation by Dry Methods.*

In the preparation of ceramic bodies by dry methods there are three distinct operations: (*a*) Pulverization of raw materials; (*b*) measurement of the materials; and (*c*) mixing the materials with water to form the body.

The clays, etc., are first dried, then ground and sifted. The grinding is performed by means of centrifugal grinders, ball grinders, crushing rolls or edge-runner mills, similar to those described, but arranged so as to obtain a product of great fineness. Any of the ground material which will not pass through the sieves is returned to the mill to be still further crushed. One of the great drawbacks to all dry-process machines is the production of a thick dust, which flies about and is injurious to the workers. The mills should, therefore, be enclosed, and ample means employed for ventilation.

Most non-plastic materials which enter into the composition of bodies are similarly ground to a dry powder by stamping machines, centrifugal grinders, stone-breakers, rollers or edge-runner mills, ball-mills, or by mills of special design, the crushed material being sifted to keep out any coarse particles.

(*c*) *Preparation by Liquid Methods* (*Slips*).

The preparation of liquid bodies or *slips* is done by one of two methods, which are distinguished by the physical condition of the materials. The first comprises four operations: (*a*) Measuring out the raw materials in the dry state; (*b*) blunging and mixing with water; (*c*) sifting; and (*d*) de-watering or stiffening the slip. The second method also consists of four operations: (*e*) Blunging the raw materials in water; (*f*) measuring and mixing in the liquid state; (*g*) sifting; and (*h*) de-watering or stiffening the slip. The two last operations of sifting and hardening are performed in the

same manner in both methods. It is often necessary to add to these a fifth operation, the pugging and kneading of the body.

The dry measurement of the materials is usually made by volume, great care being required as the bodies used for fine earthenware (fine faience) and porcelain do not allow much variation in composition.

Blunging the clay is performed in mills similar to those used for washing clay, but as only crushed or washed clays are used there is no fear of the inconvenience resulting from stones or coarse sand. The blunger shown in Fig. 19 is that most generally used, but that shown in Fig. 21 is also employed. The blunging is not done in a continuous manner, but definite quantities of clay and water are introduced, and when the mixture is homogeneous it is run into a tank or " ark."

Non-plastic materials, as quartz, flint, felspar, etc., must be ground to the required fineness before blunging. They are then placed with a suitable quantity of water in a blunger, which is kept in motion until a slip of uniform density and consistency is obtained. The slip is then run through a sieve into a tank, where it is stored until required for use.

Mixing in Liquid State.—In order to mix together two or more substances which have been blunged in water and made into *slips*, it is essential that they should have approximately the same consistency, so that they may have no tendency to separate from each other. It is also necessary to keep them in a continual state of agitation, in order to avoid settling.

In order to know the proportions suitable for mixing several slips to form good bodies, it is necessary to know the weight of dry materials which they contain in a given volume. This weight is easily obtained by drying a given volume of the body, e.g. 1 pint, at 120° C., and by weighing the dry residue thus obtained ; or it may be calculated from the weight of 1 pint of the slip if the specific gravity of the solid material is known. Thus, if P is the weight (in ounces) of 1 pint of slip, S is the specific gravity of the solid material, and D is the weight of dry solid matter in 1 pint of the slip :—

$$D = \frac{(P - 20)S.}{S - 1}.$$

Conversely, if the specific gravity of the solid material is known, the amount of it required to produce a slip of any required density or " weight per pint " can be calculated.

When the amount of solid matter in a pint of slip is known, a simple calculation will show what volume of each of a number of different slips is needed to produce a body having any desired composition. To avoid constant repetitions of this calculation, slips are usually made of a standard consistency or " weight per pint," which may be measured in different ways. Hydrometers may be employed, but are not sufficiently exact, and it is better to

weigh a given volume of the body. For this purpose a vessel of known capacity, say 1 pint, is used. It is balanced on a pair of scales with shot or other convenient material, and after being filled with the liquid it is replaced on the scales, where it is again weighed. If heavier than the standard, the slip is too thick, and a little water must be added to it; if its weight is too light, there is too much water in the liquid, and it must be allowed to settle for a short time, in order that some of the water may be poured off, or some slip of greater consistency may be added. This operation of adding water or body is repeated until a fresh determination of its "weight per pint" shows that the slip has the desired consistency. With a little practice the variations are very slight, and are often corrected at the first attempt.

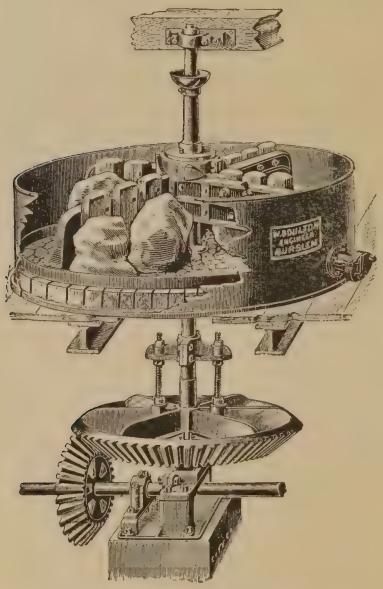


Fig. 35.—Grinding mill for flint, etc.

The different substances which are to be mixed together to form a body having been thus made into slips of definite densities, definite volumes may be measured out and mixed in a large tank or *mixing ark*, which is a simple form of blunger.

Sometimes the slips are kept in a series of tanks all the same size, and it is then sufficient to draw off each slip until it has sunk to a definite level. The measurement is effected by a stick, the marks on which are 1 in. apart, and are termed "wet inches."

A single receptacle can also be employed which is provided with index marks. The first slip is poured into this vessel until the first mark is reached, then the second slip until the second mark is reached, and so on.

In any case, the mixing of the various slips is easily effected by hand or in a blunger.

Sifting separates from the slip any coarse grains which have escaped the sieves used in blunging and grinding.

The consistency of the body, and the tendency of the grains of sand, surrounded by clay, to remain in the holes of the sieves make sifting tedious, and the sieves or *lawns* are therefore shaken and struck repeatedly. A small quantity may be sifted by hand, but in factories an arrangement such as that shown in Fig. 36 is generally used. Above the vessel intended to receive the filtered slip two slides are placed, between which is moved a frame to which is com-

municated a reciprocating motion by means of an eccentric wheel. The sieve rests on two longitudinal slides inside this frame, and is slightly narrower and shorter than the frame, so as to slide easily.

The sieves are made of silk, or, better, of bronze wire.

The slip to be sifted is brought to the sieve by a trough. From time to time the supply of slip is stopped, the sieve is removed, overturned, and struck to cause the residue to fall out into another vessel. One sifting is not usually sufficient ; the slip being usually passed through two or three sieves, each finer than the others. For large quantities, several sieves are arranged side by side in the same frame. Sometimes these sieves are replaced by a revolving screen consisting of a horizontal framework of six or eight sides covered with gauze, which allows the slip to pass through it but not the coarser particles. The slip is fed in at one end and the coarse particles pass out by the other.

Stiffening or De-watering.—The filtered body is too fluid to be

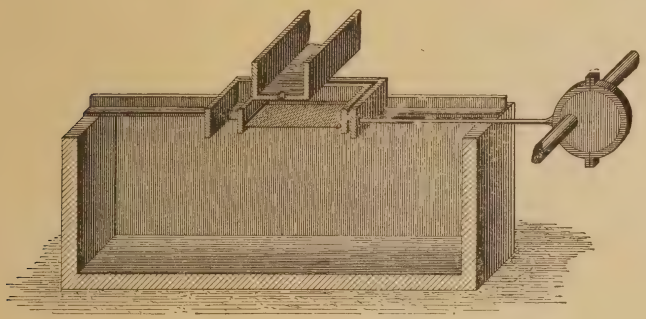


Fig. 36.—Lawn or sieve for slip.

made into shape, and unless the articles are to be made by slip-casting (Chapter V) some water must be removed from it. This operation is called *stiffening*, and may be effected in several ways, including :—

(*a*) Prolonged storage in settling tanks, and then running off the clear supernatant water ; this process is not practicable for the preparation of pottery bodies, but it is used when clay is washed for brickmaking, and in the purification of china clay.

(*b*) The slip may be partially dried by spreading it on floors heated by steam, fires, or by waste heat. In these floors, plates of cast iron, or preferably of fireclay, cover a series of stonework channels placed between the fire and chimney, and arranged so as to present a large surface for utilizing the heat in the best possible manner. The layer of slip is from 12 in. to 14 in. thick, and it must be stirred constantly during the drying. When sufficiently stiffened, the material is made into " balls " and placed in cellars for several weeks, in order that the remaining moisture may be distributed

uniformly throughout the entire mass. Other methods of drying by artificial heat may also be used.

(*c*) Slips may also be stiffened by absorbing the water from them on porous terra-cotta or plaster slabs or vessels. Those made of terra-cotta are rendered as porous as possible by adding to the body of which they are made sawdust, or any other organic substances which will burn out in the kiln. After being filled with the body they are placed on shelves exposed to the wind in order to hasten evaporation. Plaster vessels are able to absorb a still larger quantity of water. When saturated, they are scraped clean and then placed in stoves to be dried before being used again.

(*d*) The chief appliance employed in stiffening slips is a "filter press" containing bags made of strong cotton into which the liquid is pumped; the bags retain the solid matter and let the water pass through. The first presses used had the arrangement shown in Fig. 37. A series of wooden frames (from 6 to 30) are pressed one against the other by means of iron bars. Cloths with their ends

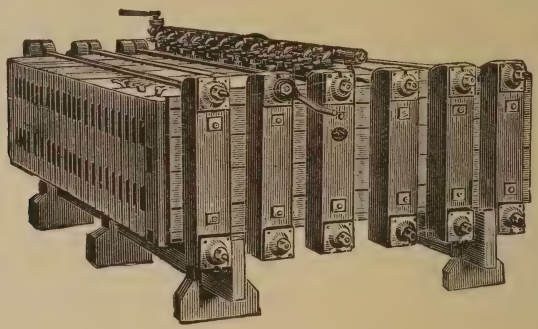


FIG. 37.—Filter press.

folded, to form bags, are placed between the frames. At the top is a pipe, which brings the liquid slip under pressure into the interior of each bag. When the pressure in each bag becomes sufficiently great, the water in the slip passes through the cloth, into the side grooves of the frames, and escapes through a series of lower apertures. The pumping of the slip into the bags is continued until they are filled with a fairly stiff paste consisting of the body from which the excess of water has been removed. The supply of slip is then shut off, the bars or clamps which hold the bags in position are loosened, the frames are removed, and the cakes of body are taken out of the cloths.

A mode of construction now preferred is that shown in Fig. 38. In another modern type of filter-press, shown in Fig. 39, the cloths are pressed between a solid disc and a frame. The body enters through a central aperture, each cloth being pierced at its centre and fixed against the disc by means of a filleted tube.

Figs. 40 and 41 show more powerful presses; the former is much

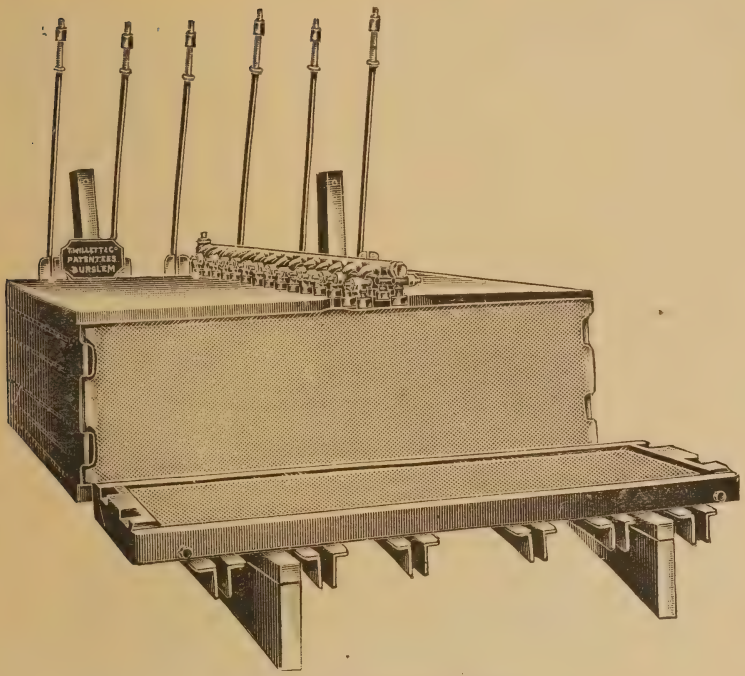


Fig. 38.—Willett's filter press.

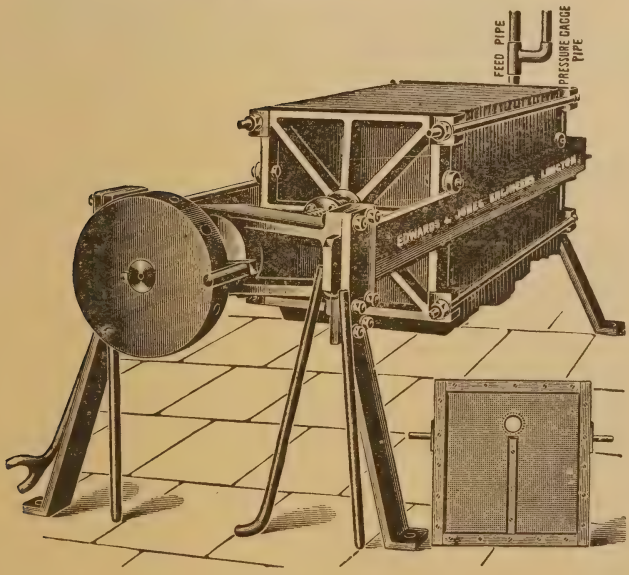


Fig. 39.—Edwards & Jones' filter press.

used in France and Germany, as well as in England, where the one represented in Fig. 41, having circular disc sliding on the frame, is also used. The pressing is done by means of a screw which has its point of support in the structure. For very large presses this screw may be replaced by an hydraulic piston. The usual sizes of filter presses are :—

Dimensions of Frames. Inches.	No. of Frames.	Volume of Body Produced. Pints.
24 × 24	6 to 24	61 to 225
32 × 32	18 to 30	308 to 572
40 × 40	24 to 40	792 to 1320

It should be observed that the more plastic the body the more difficult is it to stiffen it by means of a filter press, and it is almost impossible to remove the last 20 per cent of water from a body of very plastic clay by this means.

Each pressing takes two to four hours. After several operations the cloth must be washed, by letting a current of water circulate in the

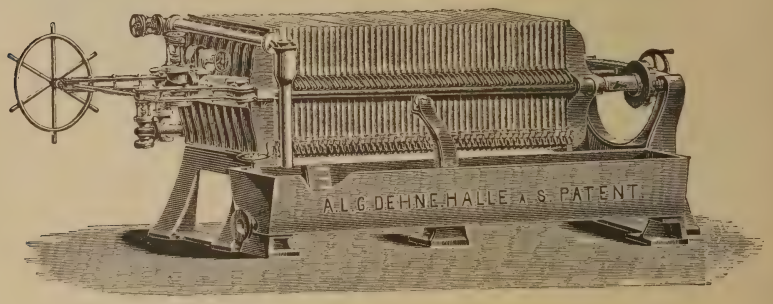


Fig. 40.—Dehne's filter press.

press, the ordinary taps for the exit of the water being closed, or by removing them from the press and washing them in a separate machine. The cloths should be preserved by soaking them occasionally in a weak solution of carbolic acid.

Membrane pumps are used to compress the slips in the press. They consist of a "plunger piston" of simple design which does not act directly on the body, but through the medium of an india-rubber membrane, rising and falling at each stroke of the piston in a case. The slip is drawn in through a ball-valve when the membrane rises, and is compressed through a similar valve when the membrane descends. A side opening in the pump (provided with a safety valve) allows the desired quantity of water to be introduced, and serves as an intermediary between the piston and the membrane. For small outputs these membrane pumps are worked by hand, for medium outputs they are worked by an eccentric wheel mounted on the transmission shaft, but when it is desired to work several

filter presses at the same time, a single pump, arranged horizontally, and driven by a pulley, is to be preferred. Other forms of pump are also used.

The cakes when taken from the filter presses have generally the consistency of a soft paste ; in some works they are partially dried by arranging them on shelves in well-aerated rooms, heated by hot air.

The filter-press cakes—either in the natural state or after drying—must be pugged so that the material may be made as uniform, homogeneous, and compact as possible. For this purpose, any of the different pug-mills previously described may be used, but the

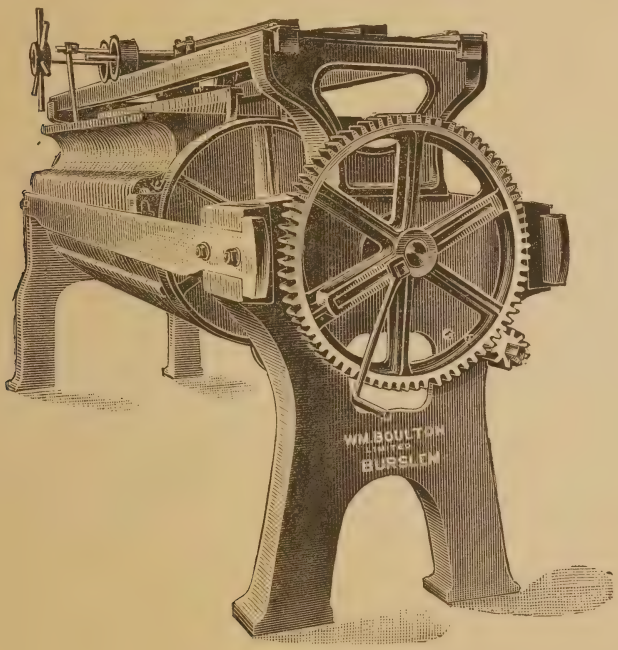


Fig. 41.—Boulton's filter press.

vertical pug-mill shown in Fig. 42, or the horizontal one shown in Fig. 28 is frequently preferred. Unless the press-cakes are well pugged, the ware from them tends to crack.

Wedging and Slapping.—" Wedging " consists in cutting the paste into small pieces with wires and throwing them forcibly on to each other (" slapping "). The paste so formed is kneaded into a uniform mass, the operations of cutting and kneading being repeated as often as is deemed necessary.

In order to assist in removing air-bubbles which, if left in the paste would spoil fine and thin ware made from it, the paste is " wedged " and " slapped " by hand, though for large outputs this

long and laborious work is replaced by *tempering* the paste in a pan- or edge-runner mill (Fig. 13) with a solid revolving pan 3 to 9 ft. in diameter, provided with light edge-runners 16 in. to 4 ft.

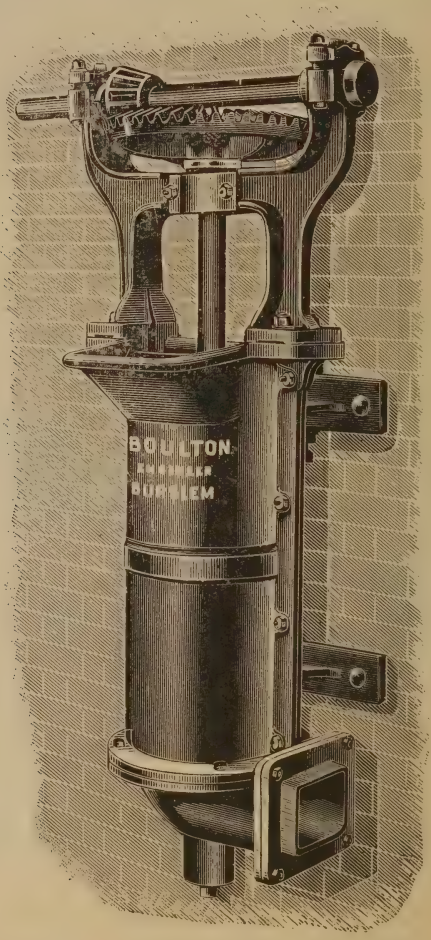


Fig. 42.—Vertical pug-mill for press cakes.

in diameter. After about twenty to fifty minutes' treatment in such a mill a very uniform paste is obtained. As such treatment is costly, it is often omitted.

CHAPTER V.

SHAPING.

By the term *shaping* is meant the whole of the operations to which plastic bodies are subjected in order to give them the shape of the articles to be manufactured. According to the nature of the article, the process of shaping is accomplished in one or several operations. If the ware is to be valuable, the shaping should usually be preceded by "wedging" and followed by "slapping" (p. 107).

The method of shaping which, at first sight, appears the simplest is that which is done exclusively by hand, with only the assistance of a few simple tools. This process is now only used for the making of original models: a few words will be said about it when dealing with the decoration of pottery ware. Apart from this, shaping can be done by four processes—throwing, jolleying, moulding and extrusion.

Throwing is based on the use of the potter's wheel; it can only, therefore, be used for the making of round or oval objects. The body should be stiff enough for the article not to lose its shape under its own weight, yet it should be soft enough to yield easily to the pressure of the hand. Articles are sometimes made in a single operation; others are first shaped by throwing, and afterwards, when the body is stiffened, they are "turned" on a lathe.

In *jolleying*, the body is pressed out by means of a profile, having the outline of the article to be made. The body used is generally semi-soft, but sometimes the jolleying is done with a semi-stiff or stiff body.

Moulding is the term applied to the process of shaping by means of moulds, the interiors or exteriors of which correspond to that of the articles to be made. Articles of any shape which can be readily removed from the mould can be made in this way.

In moulding by hand the body, having a soft or semi-soft consistency, is placed by hand into or on to the mould and is pressed to shape.

In moulding by jigger or jolley—employed for round or oval articles—the semi-soft body receives the desired form partly by moulding and partly by applying a profile attached to a "jigger" or jolly.

In moulding by press, or pressing, the body is compressed in the interior of the mould, and can be semi-soft, semi-stiff, stiff, or dry, according to the pressure exerted. Before a soft or pasty body can

be shaped by pressing it must usually have been given a preliminary shaping by one of the three processes previously mentioned. A dry or semi-dry, on the contrary, may be placed directly in the press.

In moulding by casting, the liquid body or slip is poured in a mould of porous material such as plaster of Paris. Like pressing a dry body, casting only requires a single operation.

In *extrusion*, the paste is forced by pressure through a die or mouthpiece of the requisite shape, the extruded material being then cut into pieces of suitable length. This method is used for bricks, tiles, wall-copings, etc.

Whichever process may be employed, the shaping is often followed by a finishing or " fettling " of the surface—usually after the article has stiffened slightly.

(*a*) *Throwing.*

Potter's Wheels are of two kinds : those which are put in motion by the thrower or by an assistant, and wheels which are mechanically driven.

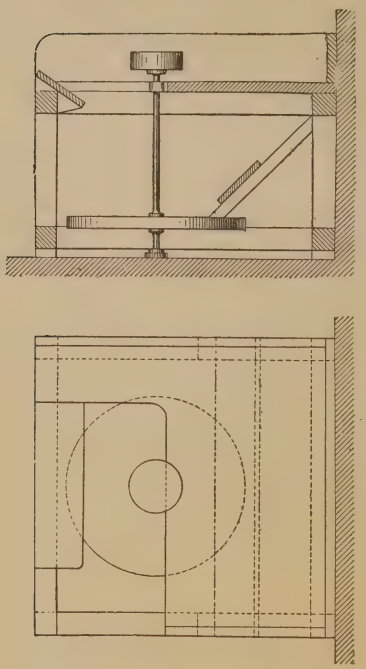


Fig. 43.—Potter's kick-wheel.

The simple potter's wheel consists (Fig. 43) of a verticle spindle, the lower end of which rests on a footstep fixed in the ground, the upper part being secured by a collar fastened to a table. This spindle is surmounted by a small disc called the *wheel-head*, which carries the body from which the piece is to be made, and at its lower end it has a heavy solid fly-wheel which the workman sets in motion with his feet. The thrower sits on a small inclined board placed near to the level of the table, and can rest his feet, when the wheel has the desired speed, on another inclined board. The speed of the wheel can, at any moment, be augmented by giving a fresh impetus, or diminished by allowing the foot to rub on the fly-wheel. Numerous modifications of this wheel exist, in one, the upper part of the wheel is held by a piece of wood under the seat of the thrower, who sits astride ; the fly-wheel is smaller but thicker, and the workman rests his feet on two pieces of wood at the side.

When large or very accurately shaped pieces have to be thrown, a steadier running of the wheel is ensured by its being driven by an assistant by means of a handle, as shown in Figs. 44 and 45. A certain amount of skill is necessary to enable the assistant to regulate properly the speed of the wheel to the requirements of the thrower, a constant speed being almost useless.

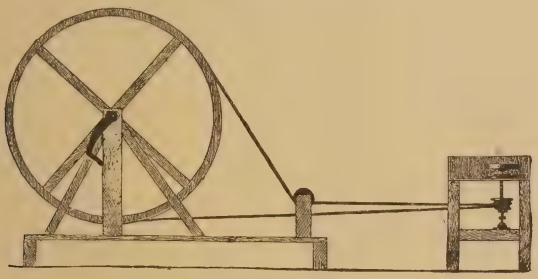


Fig. 44.—Potter's string-wheel.

Mechanical Wheels.—For large outputs, especially where great accuracy is not required, hand-driven wheels are replaced by those mechanically driven, though the shaping of the articles is always done by hand. When small objects of simple shapes are to be made, wheels of constant speed may be used, a simple belt drive being employed as shown in Fig. 46. The wheel is started by a workman placing his foot on the pedal, it being brought to a standstill automatically when he ceases to touch the pedal. Fig. 47 shows an inverse arrangement, the wheel being started when the pedal is depressed. It is possible to vary the speed of the wheel either by altering the diameter of the pulleys or by inserting intermediate conical drums, but when, in consequence of the dimensions of the body to be thrown, or of other difficulties, it is necessary that the thrower should be able to modify the speed at any moment as he does on the string- or cog-wheel (Figs. 44, 45), a speed-changing device must be used. For instance, the wheel may be driven by a pinion, whose point of contact can be displaced from the centre to the circumference of a revolving disc as shown in Fig. 48. A counterpoise brings the pinion towards the centre and reduces the speed, while the thrower, by pressing a pedal, increases the speed to suit his requirements.

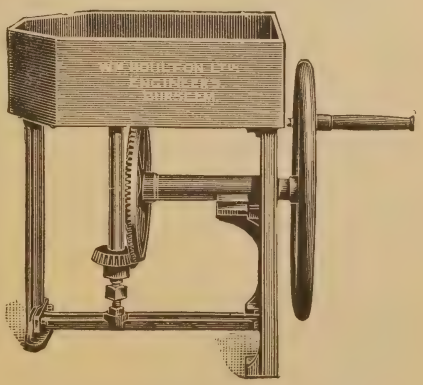


Fig. 45.—Potter's geared-wheel.

When the throwing requires very little power it is preferable to make use of the very simple arrangement shown in Fig. 49; the driving pulley being mounted loosely on the spindle and having a

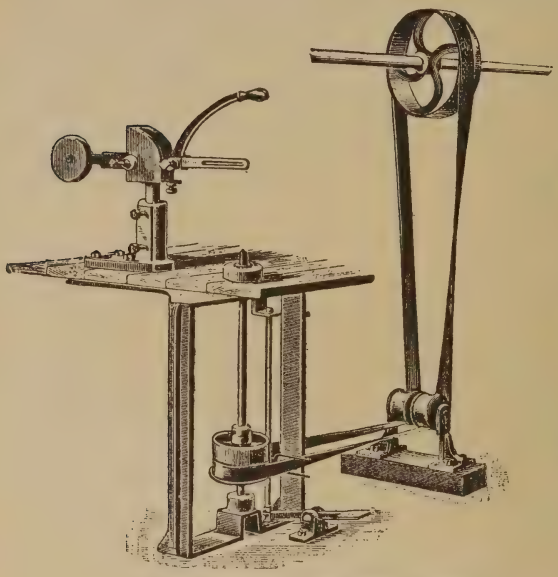


Fig. 46.—Power-driven wheel (jigger).

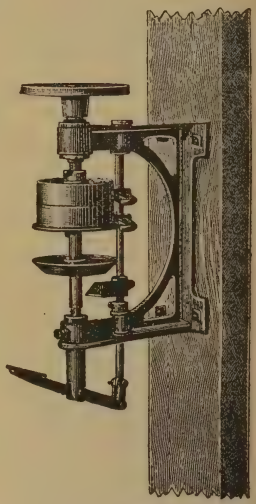


Fig. 47.—Power-driven wheel.

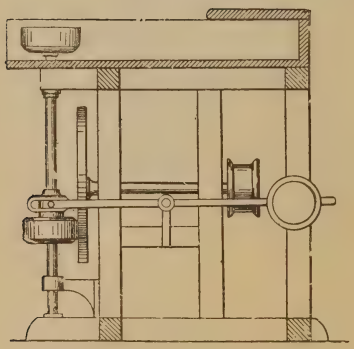


Fig. 48.—Power-driven potter's wheel.

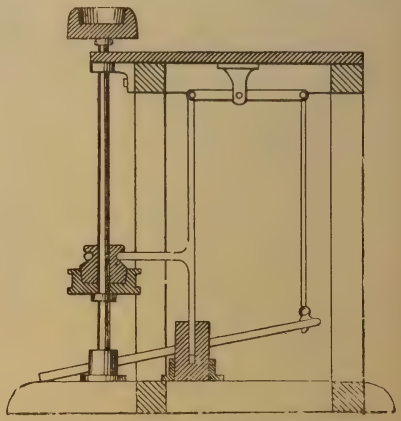


Fig. 49.—Power-driven potter's wheel.

conical space into which a conical piece fitting tightly on the spindle can penetrate, and be raised and lowered by means of a pedal. When the pedal is free the two cones fit together and the wheel

revolves at its maximum speed. If the thrower presses the pedal lightly, the contact is less perfect, and the speed is slackened. If, finally, he presses more heavily, the contact ceases and the wheel stops.

The cone drum-wheel constructed by Boulton (Fig. 50) solves the problem in a more complete manner, but is of a rather complicated design. On the spindle of the wheel is a cone which can be set in motion by another cone placed in a contrary position, having a slightly arched surface, and displaced at the same time as a frame, the ends of which are caught in two slides, an upper and a lower, fixed in the structure. This second cone has a continuous and

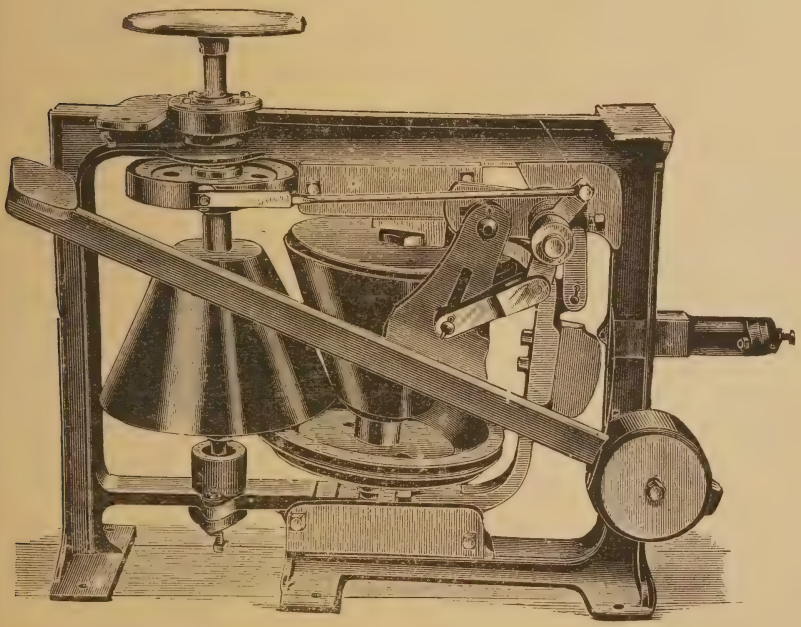


FIG. 50.—Cone-driven potter's wheel (Wm. Boulton, Ltd.).

rotary movement, caused by a thick rope passing on a grooved pulley on the spindle. A pedal is fixed to the frame, and its counterpoise tends constantly to bring the mechanism into the position shown in the figure, in which the two cones are not in contact, the wheel being consequently at rest. If the thrower presses on the pedal, he causes the frame to turn slightly and pushes it against an elastic spring contained in a horizontal cylinder fixed to the back of the structure. Under the influence of this spring the frame is pushed forward and the small circumference of the driving cone comes into contact with the largest circumference of the cone fitted on the spindle of the wheel, to which it communicates the least speed of which the apparatus is capable. If the thrower increases

the pressure on the pedal, the oscillating movement of the frame continues and the increasing circumferences of the driving cone come successively into contact with the decreasing circumferences of the other cone, so that the speed increases until it reaches a maximum. The thrower can thus, by regulating the pressure on the pedal, and without great effort, vary the speed at will. For wheels of large dimensions a check, mounted on the spindle of the wheel, stops the movement when the pedal is left to itself.

Mechanical wheels are usually so arranged that all may be driven by the same rope.

Processes of Throwing.—The thrower takes a quantity of pasty body, proportionate to the size of the object to be made, and places it on the wheel-head. He then sets the wheel in motion and, after

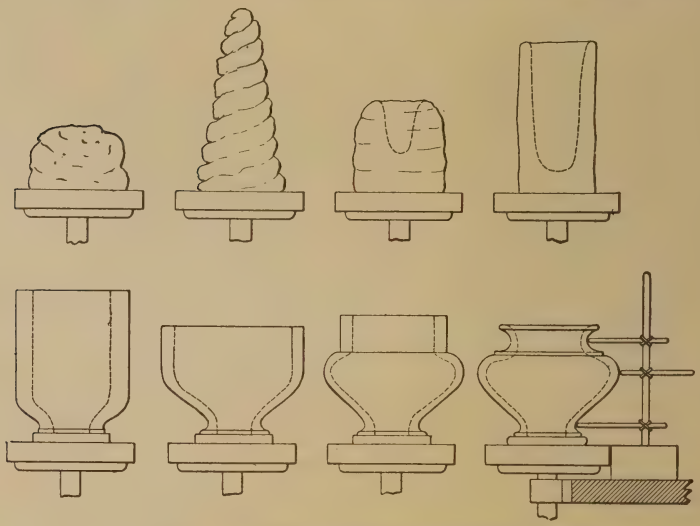


Fig. 51.—Stages in process of throwing a vase.

having wetted his fingers, he presses the mass horizontally and forces it to " rise and fall " several times, then with the thumb on one part and the fingers on the other he makes it gradually assume the desired form. This operation, which at first sight appears very easy, requires much practice to press the mass uniformly, and to prevent knuckle marks, a defect which is known as " twisting." He must know how to regulate the speed of the wheel to the ascending or descending movement which he gives to the body with his hands, and must, by suitable sprinklings, prevent the body from drying unequally in contact with the fingers. When making an article accurately to a prescribed shape or size, the thrower may place a model of it on the table in front of him. For the principal measurements he uses an instrument called a *gauging rod*, which, as shown in the lower part of Fig. 51, consists of a vertical rod fixed on a

stand and holding horizontal rods, and so gives at the same time both the height and the distance from the side of the wheel-head. Throwers use small tools of metal, wood, slate, or horn to give more precision to the moulding, to sink certain contours, or to sharpen the edges.

The throwing is generally completed by smoothing the surfaces with a small sponge, lightly applied, and by polishing them with a steel or horn blade. When the article is finished the thrower

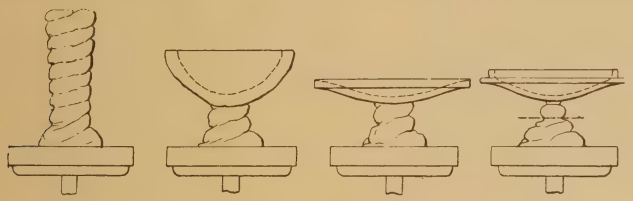


Fig. 52.—Stages in throwing a flat cover.

detaches it by passing an iron wire between it and the top of the wheel (as shown at *m*—*n* in Fig. 53), and then places it on a board to be taken to the drying room. When the article is too heavy to be thus removed without risk of squeezing it out of shape, this board is fixed on the wheel-head previous to the throwing being commenced.

Fig. 51 shows the various stages in the throwing of a vase and Fig. 52 that of a flat cover. The making of difficult pieces requires a very plastic body, such as those generally used in the manufacture

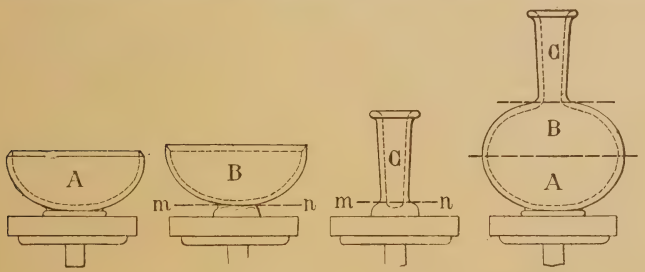


Fig. 53.—Stages in throwing a decanter.

of terra-cotta, stoneware, or fine earthenware. With a lean body, such as porcelain, complicated pieces must be made in several parts, which are afterwards fastened together. Fig. 53 shows the making of a decanter in three pieces. The parts to be joined are scratched in order to increase the surface of the joint. Usually the thrower makes several pieces of each kind, then, when the body has stiffened a little, he wipes the surfaces to be joined, using a very wet sponge, brings the parts together, and presses them firmly into contact.

Sometimes the process called "throwing by cord," as shown in Fig. 54, is used. Round a vertical rod a cord is rolled with varying thicknesses according to the shape of the interior of the article. The body is then applied to the cord and roughly shaped by the hands. After it has stiffened a little the article is turned accurately to the required shape on the lathe, and after leaving the body to harden still further, the cord is unwound and comes away entirely, leaving a hollow interior with a shape corresponding to that occupied by the cord.

Shaping by Profile.—It is sometimes convenient to shape articles either on a potter's wheel or in a mould by means of a "profile" (that is to say, a flat strip of metal in one side of which the outline to be made is cut out). This profile is made gradually to approach the mass to be shaped and, on coming in contact with it, the profile removes the superfluous body and produces an article having the

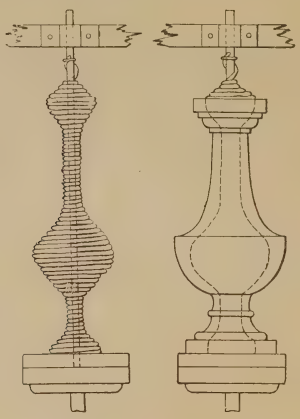


FIG. 54.—"Cord throwing."

FIG. 55.—Profile.

exact form of the profile. Fig. 55 represents a profile used for making the exterior of a baluster of which the interior is shaped by "cord throwing," as shown in Fig. 54. It should be observed that a complete "profile" of this kind can only be used when the piece is supported internally as in Fig. 54, or externally in a mould, because the body is too soft to resist the lateral pressure of the profile.

Oval or square bodies can also be thrown, though this process is seldom used except for fancy articles, pieces being manufactured with much greater precision by means of moulds.

Turning, or shaping by means of a lathe, is employed—

(1) For giving a very exact form to articles made of a plastic body.

(2) For making articles of a lean body which must be made thick because of its feeble cohesion.

Before it is fit for turning, the body must be sufficiently hard

not to lose its form during the process, yet soft enough to allow the finger-nail to make an impression. To ensure their having the desired consistency, the pieces waiting to be turned are kept in a cellar or other cool place having a constant humidity.

Both vertical lathes and horizontal lathes similar to those used for turning wood or metal (Fig. 56) are used for turning pottery. The tools are small blades of steel, of various shapes fixed to a wooden handle. Compasses or calipers are used to measure the diameter or thickness of the article.

Turning is an easier operation than throwing, and can be quickly learnt. The body must be cut, not scraped, and when it becomes too dry and apt to break it should be damped with a small sponge. The piece is finished by polishing it, whilst still on the lathe, with a blade of steel or horn.

When turning porcelain or other lean bodies, a dust is produced which is very disagreeable and injurious to the health of the workers,

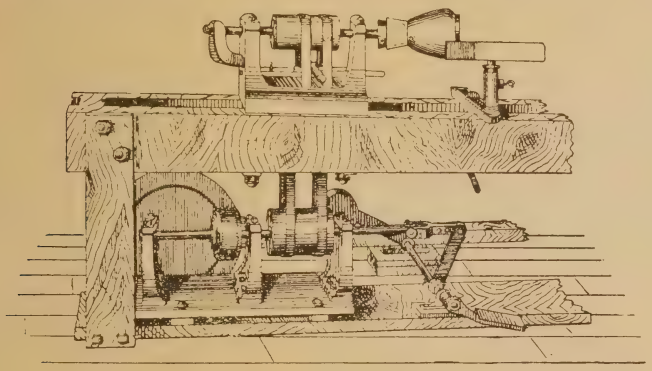


Fig. 56.—Horizontal lathe.

who should be provided with masks, or, better, with an exhausting fan and hood arranged to carry off this dust.

(*b*) *Extrusion or Expression.*

The process known as *extrusion* or *expression* is employed for making articles of a symmetrical shape, about one axis, as pipes, bricks, hollow blocks, and some tiles.

The machines used consist of three essential parts :—

(1) The *die* or *mouthpiece*—the aperture through which the body is forced.

(2) The *propeller* or mechanical part, for compressing the body.

(3) The *cutting apparatus* by which the article is cut to the desired length after coming out of the die.

When the articles to be expressed have a simple section, as a brick, the die is formed of a slab of metal or hard wood, in which is cut an aperture having the form of the article to be produced.

The opening must be rather larger at the back where the body enters, and it is wise to round the angles slightly, and to smooth the interior of the die.

Figs. 57 and 58 show two dies, one for expressing a 2-in. cylinder of clay and the other a square brick with rounded edges. The wider part of the opening is $\frac{1}{10}$ to $\frac{1}{5}$ of the thickness of the die larger than the other. A similar arrangement is also used when the objects to be expressed are hollow, but a piece called a *bell* is placed in the aperture and held in place by means of a rod and an iron *bridge*. This bell is shaped like the section of the hollow space in the article to be made. Fig. 59 shows a die of this kind used for making pipes, the bell being in the form of a disc of such a diameter that there is a ring-shaped space between it and the circular opening in the die. The iron bridge must be placed so far behind the aperture of the die (6 in. to 12 in.) that the body after being divided by it may be rejoined under the influence of the pressure of the propeller and of the compression which the body experiences during its expression through the die. In order to divide the body as little as possible, the bridge usually has a section indicated by the sketch *a—b* (Fig. 59).

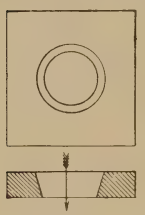


Fig. 57.—Cylinder die.

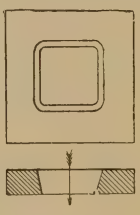


Fig. 58.—Square die.

When the article to be made must have several spaces or hollows

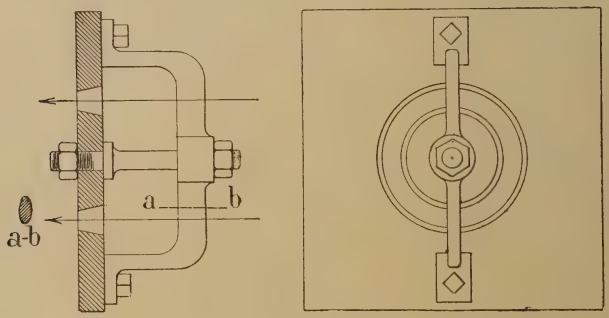


Fig. 59.—Pipe die.

in it, a corresponding number of bells are used, held by one or more bridges. Fig. 60 represents the arrangement employed for the expression of a hollow block with six hollows.

The construction of dies is a delicate matter when articles which are much smaller than the machine are to be expressed. This is due to the fact that the body admitted into the die by a uniform pressure creates friction along the walls, which consequently retard its movement. Owing to the cohesion of the clay, this resistance is

transmitted to the whole of the mass, where the orifice is not too large, and beyond a certain limit the body, instead of advancing uniformly, travels more quickly at the centre than at the sides and especially than at the corners. When the difference in speed is not too great, differences of density result, and cause the ware to lose its shape during drying and firing. If the difference in speed is sufficiently great a series of tears or serrations at the corners is produced, as shown in Fig. 61; these are sometimes called

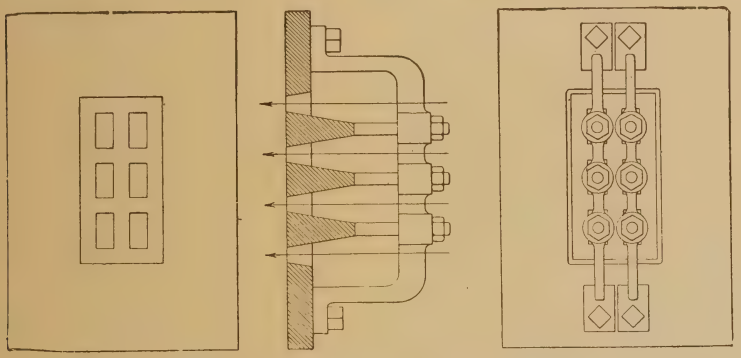


Fig. 60.—Die for making hollow blocks.

" dragon's " teeth. This defect may be remedied by increasing the resistance at the central parts, and by reducing it as much as possible at the angles, by the use of " cheeks " of cast iron or phosphor bronze attached to the outside of the die. They should be longest at the centre of the upright parts, and disappear at the angle.

Dragon's teeth may sometimes be prevented by lubricating the die with water or oil contained in a vessel above the die, and communicating with it by means of a pipe and a tap. The chief difficulty consists in making the water or oil flow uniformly over all the surface without the openings for the entry of the water being stopped by the body. A type of lubricated die or mouthpiece which is largely employed is shown in Fig. 62.

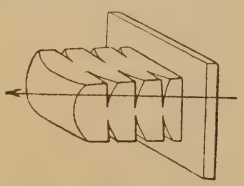


Fig. 61.—Clay issuing from faulty die.

In an exterior conical box are placed several wood frames forming a series of ducts communicating with each other and with the tap through which the water enters. On the frames, plates of zinc are placed so as to overlap each other, so that the water can flow between them in a very thin layer, and so lubricate the body as it pasess through the die.

The construction of dies for large articles is often difficult, because their different proportions depend on the plasticity and consistency of the body used, but it is nevertheless very desirable that ceramists should learn to make the dies they require so as to

be able to use the shapes best suited to their requirements, and not to have to rely entirely on the makers of the machines.

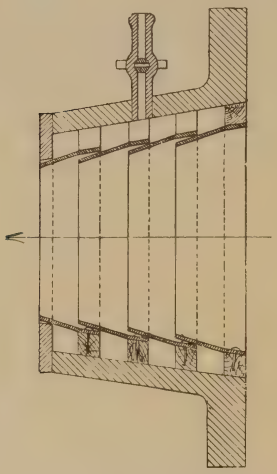


Fig. 62.—Water-lubricated mouthpiece.

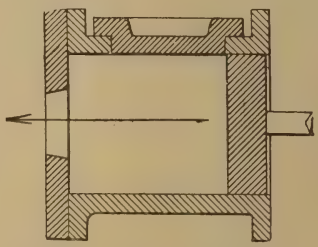


Fig. 63.—Section of "Stupid."

The *propeller* or *press* used for compressing the body through the die may have one of five forms :—

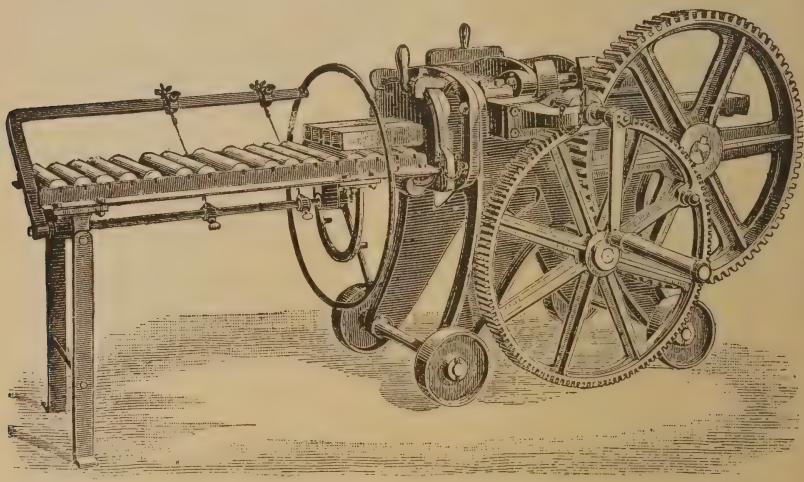


Fig. 64.—"Stupid" for small pipes and blocks.

(1) Piston propellers or plungers ; (2) blade propellers ; (3) single-screw propellers or auger machines ; (4) twin-screw propellers ; and (5) cylindrical propellers or *expression rolls*. In each case, the pro-

peller is contained in a case—sometimes known as a *barrel*—the whole forming (i) a *running-out machine* or *stupid ;* (ii) a *pug-mill ;* or (iii) an *expression rolls machine.*

Piston propellers are used in what are known as *running-out machines.*

Plunger-press or *stupids* (Figs. 63, 64).—They consist of a rectangular box or chamber, at the front of which is a die or mouthpiece, and at the back is a piston. The body is introduced into this chamber through an opening, sufficient body being put in to fill the box completely ; it is then closed by means of a cover. The piston is then set in motion in the direction indicated by the arrow (Fig. 63), thus forcing the body out through the die. When the piston has reached the end of its course it is brought back and the operation of filling the machine with body is repeated, the working being intermittent. The movement of the piston can take place horizontally as in Figs. 63, 64, or vertically as in Fig. 65. The piston may be moved by hand or power, the latter being applied either by a pulley or through the direct pressure of steam on the piston.

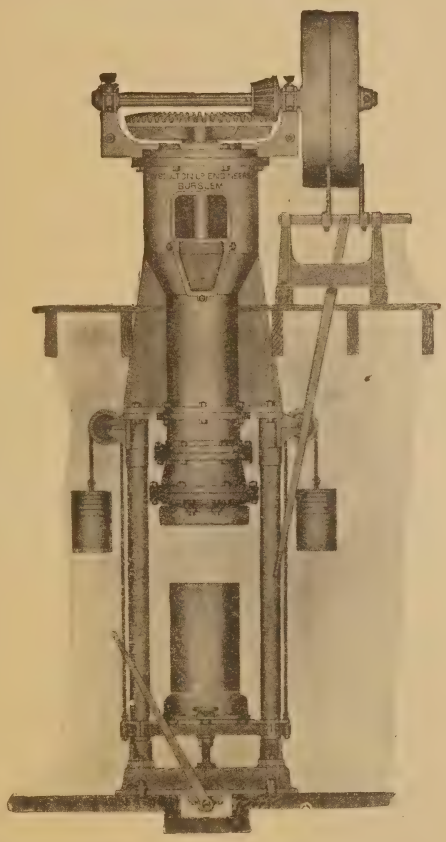


Fig. 65.—Vertical plunger machine for large pipes.

Blade propellers are similar to the pug-mills shown in Figs. 27 to 30, the die being fitted to the exit end of the mill, and the blades nearest to the die serving as propellers. The body is thrown into the top of the mill and, when pugged, passes out at intervals corresponding to the passage of each blade behind the die.

Single-screw propellers or *auger machines* are frequently used, and consist (Fig. 66) of a cylinder closed at one end, the other being fitted with a die ; inside the cylinder is a screw or worm. The

material enters the cylinder and is progressively compressed towards the front and forced out by the screw. The diameter of the cylinder, the speed of the screw, and the size of the die must be accurately adjusted to suit the body, as the latter will not be properly compressed if the die is too large. If, on the contrary, the die is so small that the body cannot pass out properly, the screw will choke, and will

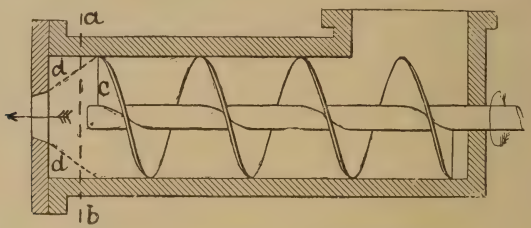


FIG. 66.—Propeller or auger machine.

eventually draw the mass round with itself without propelling it forward. The pressure on the section *ab* (Fig.) 66 is not constant, as each turn of the screw propels a fresh quantity of body, which is pressed forward most at its extremity. At any point of the section *ab* the pressure is therefore greatest when nearest to the end *c* of the screw, and least when *c* is furthest from *a* or *b*. To avoid the irregular expulsion which would result if they were close together, a certain distance is left between the end of the screw and the die so that the pressure may become uniform.

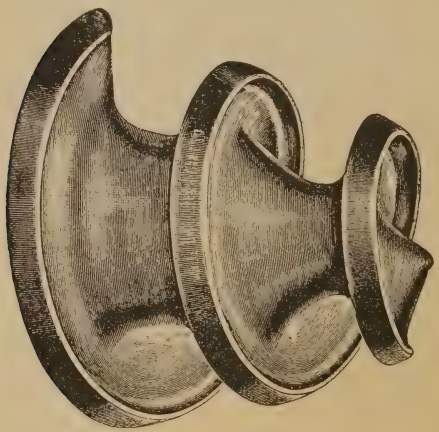


FIG. 67.—Worm propeller.

This distance must be sufficient, but not so great as materially to increase the resistance. As the clay remains motionless in the corners *d*, *d*, and only advances in the form of a cone, the friction produced between the part not in motion and the propelled body is very great and may stop the machine if the cone *d* is too long. This difficulty can be greatly decreased by making the screw at the end of the cylinder conical as shown in Fig. 67, so that the screw may approach nearer to the die.

Screw propellers are frequently combined with horizontal pug-mills (Figs. 28 to 33), the same machine being used for both pugging and shaping. For this purpose, half the shaft is provided with "blades," and sometimes with *counter-blades* (Figs. 29 and 30), the

other half being in the form of a screw or worm made in several pieces, or of a conical helix. Screw propellers are seldom moved by hand ; steam power applied through a pulley is usually employed. They are largely used for making bricks and hollow blocks, pipes, and many articles which are afterwards more accurately shaped by pressing. Unfortunately, they require a considerable amount of power to drive them, and articles made by them often have a helicoid structure.

Twin-screw propellers are similar but have parallel screws, turning in a contrary direction to each other and compressing the material through a single die, the object being simultaneously to pug and shape the body, though the very slight pugging thus obtained by means of the tangent worms must not be confused with the much more efficacious action of a trough-mixer with two shafts, the blades of which intersect each other as previously described (Fig. 31). A twin-screw propeller has the further disadvantage of producing

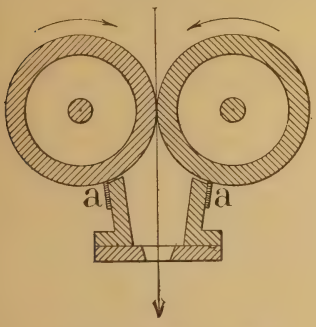


Fig. 68.—Vertical die and expression rolls.

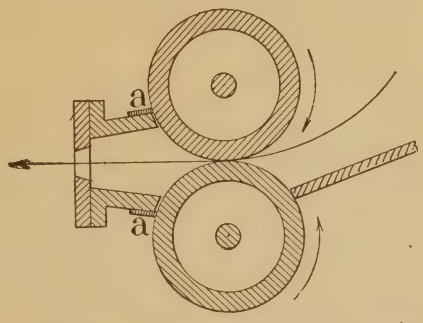


Fig. 69.—Horizontal die and expression rolls.

two parallel currents of paste, which the compression of the die does not always weld together.

Expression rolls are usually arranged in pairs (Figs. 68, 69, 71), but sometimes three rolls are arranged in a set (Fig. 71) as well as the die through which the body issues. These machines are power-driven, are simple in construction, yield pastes of more uniform texture than screw propellers, and absorb less power. The joints between the die and the rolls are made by sheets *a*, *a*, *b*, *b*, fixed by bolts, and kept in contact with the rolls as they wear. In spite of these precautions it is difficult to obtain tight joints ; leakages of clay absorb power and make the machine dirty, and this is the chief difficulty experienced in using this type of shaping machine.

Cutting Machines.—The body, on passing out of the die, has the desired section, but must be cut to the requisite length. It is received on a " table " provided with rollers of metal or wood covered with oil, felt, or plaster. If the propulsion of the body is intermittent or is stopped at the time of cutting, an apparatus with fixed cutter (Fig. 72) may be used. The cutter shown in Fig. 72

consists of a frame, on which are stretched steel wires passing through the table, their distance apart being equal to the length of the articles to be made. A portion of the extruded body of convenient length is cut off and pushed forward on to the table, and when it is at rest, a workman moves the handle (shown on the right of the machine)

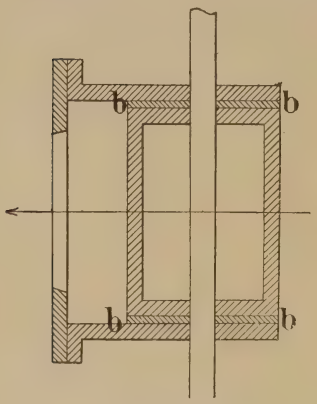


Fig. 70.—Plan of Fig. 68.

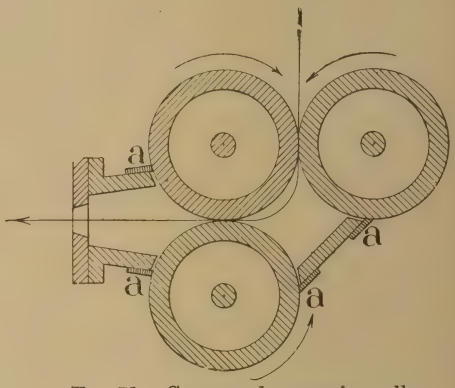


Fig. 71.—Compound expression rolls.

and by this means forces the mass of body past the wires, which cut it into pieces of the required length; these are afterwards removed by hand. The pushing device is then replaced in its original position. Instead of pushing the mass past the wires, the latter may be attached to a frame which turns on a pivot so that the wires are forced to pass through the mass. This arrangement is more extensively used on the Continent than in this country; it gives a cleaner cut, and is generally preferable.

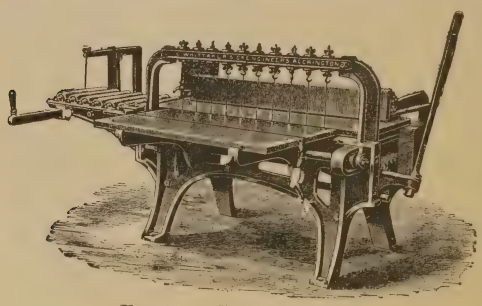


Fig. 72.—Cutting table.

It is sometimes more convenient to use a table with a movable cutter (Fig. 73) which consists of a fixed table and a second—termed a *wagon*—mounted on four wheels, which run on rails. The band of clay or body is received on the first table and passes on the wagon which is placed close to it. The clay tends to push the wagon forward, but the workman keeps it fast until the clay has reached the end of it. He then allows it to advance with the same speed as the clay, and cuts the latter by operating the pusher or, in another type of cutter, by drawing down the frame carrying the steel wires. The articles are then removed and the man pushes the wagon back to its original position.

When the propulsion is effected vertically, as in Fig. 65, the body is received on a balanced table which descends until the extruded mass has the desired length. The machine is then stopped

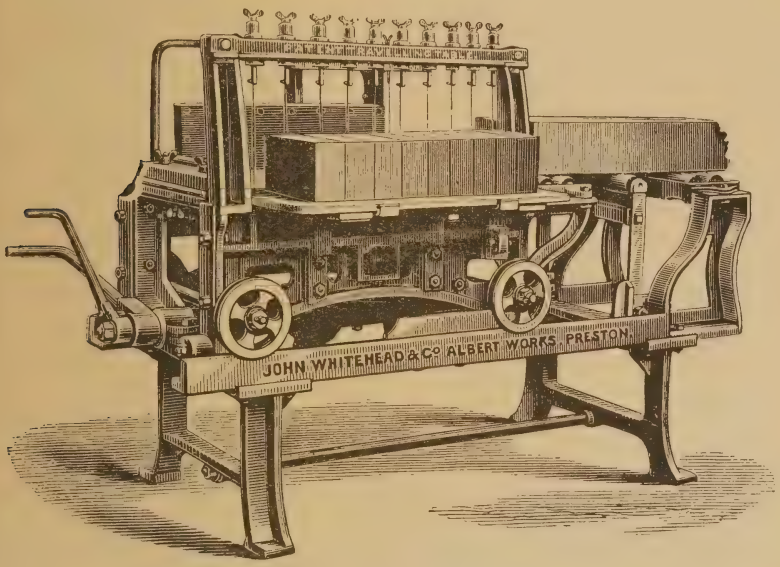


Fig. 73.—Movable cutting table.

and the clay is cut by a steel wire stretched in a horizontal frame. The cut piece is removed and the table returns to its original position under the influence of a counter-weight.

(*c*) *Moulding by Hand.*

Wooden Moulds.—When the articles to be moulded by hand are similar to bricks or slabs in shape, wooden moulds are used ; these moulds may be in one or in more pieces, according to the shape of the article.

The simplest mould is that used for ordinary bricks ; it consists of a wooden frame (Fig. 74), the shape of the brick to be moulded. The moulder places this frame on a wooden table, then takes a quantity of body—which must be in the form of a soft paste—throws it violently into the mould, compresses it with his hands so as to fill the corners, and smooths the upper surface with a piece of

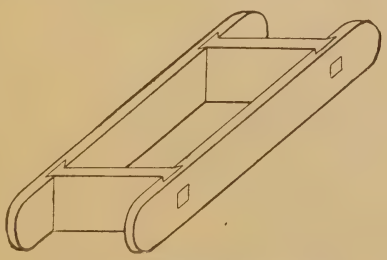


Fig. 74.—Wooden brick-mould.

wood termed a *strike*. The mould is raised and turned first on its side and then emptied on to a *pallet board*. Prior to being used, the mould and the surface of the table are damped or sanded to prevent adhesion. Metallic hinged moulds are also used ; this special process of making is described in Chapter X.

Bricks of all shapes and sizes, tiles, plaques, etc., may be moulded in this way if the body has the desired degree of plasticity, is not too soft, and fills the mould well, particularly the lower corners. Articles with intricate grooved parts, or which would require complicated moulds, are made roughly to shape in a simple mould and, when sufficiently hardened, they are finished with manual tools.

Plaster Moulds.—When the articles to be made are irregular in form or are ornamented, plaster moulds in either one or more pieces are used. Plaster is, in fact, the only material which can be used satisfactorily, as it does not adhere to the soft clay body. Formerly, moulds made of biscuit ware were used, but they have been abandoned as they make manufacture more difficult and more laborious.

The plaster used should be good, superfine plaster of Paris, and must be kept in a dry place. The mould is made from a model representing exactly the article to be made, but slightly larger to allow for the shrinking of the body (see Chapter VI). If the article has " undercut " parts which would prevent it leaving the mould, it would be necessary for these to be first stopped up with plastic body or wax, and removed after moulding. When many articles all alike have to be made, a model of plaster may be used instead of one made of clay ; such models must be greased or oiled before being cast, a solution of soap and olive oil being often used for this purpose. To prevent the plaster model from absorbing too large a quantity of the fat, it may be first coated with a solution of resin in alcohol. Clay models do not require any preparation, though some mould-makers paint them with a mixture of soft soap, tallow, and water, but the dampness of the plaster spoils them, and they can only be used for a single casting.

Unless the article is of a simple form, the mould must be made in several pieces. This division is made by cutting away the plaster, or by placing sheets of pasteboard or metal at the joints and making one part of the mould at once. In order to join again the pieces of a mould, their exterior surfaces are dressed, and a casing of plaster is run all round.

The first mould obtained by casting from the model is only used for moulding when a small quantity of pieces are to be made. Usually it is called the " master mould," and is only employed to cast other models in plaster, from which, in their turn, working moulds are cast. Plaster moulds wear rapidly, in consequence of the constant dampness they absorb from the body, and because of the mechanical weakness of plaster. They may be made stronger by mixing some alum with the plaster.

The making of moulds needs special care, because it is essential that the plaster should always have the same consistency, so that

its absorbing power may be always the same. If, of two moulds made from the same model, one has been made with thick plaster and the other with thin plaster, the latter will be more absorbent, it will dry the body more quickly, and will give denser wares having less shrinkage. This defect will be more serious if the mould be of such large dimensions that it has to be made in several pieces, unless the precaution is taken of each time adding the same proportion of water to the plaster.

The thicker the plaster mould, the more water it can absorb, and it is well to proportion this thickness to that of the wares. If the latter have narrow parts beside thicker ones, it is necessary to take this into consideration, or some would dry before others, causing warping and cracks ; alternatively, certain parts of the mould may be moistened before use to make them less absorbent.

It is also desirable, in deciding the form to be given to moulds, to take into consideration the shrinkage of the body, as this must always be allowed to take place freely. When the shape of the object would be opposed to allowing this condition to be fulfilled, the mould must be made in several pieces, so as to be able to remove, after the making, those which would impede the shrinkage.

If a mould were too absorbent in consequence of the great porosity of the plaster or its too great thickness, it would produce the same difficulties as too rapid a drying. The remedy would consist in diminishing the thickness or in mixing the plaster more strongly, or, finally, in moistening it sufficiently. In pressing by hand in plaster moulds, the workman throws pieces of body into the mould, pressing them with his hand, or with a sponge if the body sticks to his fingers. A rough sheet of body of uniform thickness, called a " batt," is often made by placing a mass of body on a prepared and moist table, and beating it out to the size of the " batt " desired. Two rules or straight-edges, the thickness of which determines that of the " batt," are arranged a suitable distance apart, and the body is beaten between them. The surface is smoothed with a roller of damp wood run on these rules. The " batt " is lifted by hand and applied to the mould, but with complex moulds it is preferable to cut pieces corresponding to various parts, and to beat them by hand against the moulds. For lean bodies, a cloth, or preferably, a damp skin, is spread on the table and used to convey the " batt " to the mould, without the risk of breaking it. Sometimes the " batt " is replaced by a piece of clay shaped on the potter's wheel, which is placed in the mould. This piece is called a " cover," and it is applied to the mould either with a sponge or by hand.

Fig. 75 represents a panel moulded in one piece by applying a suitable-sized " batt " to the mould, and by forcing it by the hand or with a sponge to take the form of the mould. When the mould is properly filled, the excess of clay is cut off with a wire, the surface smoothed, if desired, and the mould with its contents is set aside to dry ; when the article is ready to be detached, in consequence of its shrinkage, the mould is turned upside down, and the moulded piece is received on a board, where it remains until quite dry.

Fig. 76 represents the moulding of a panel of more complex form, and made in three pieces. The first is made in the mould A, as in the preceding case; the part of the "batt" which is found above the central aperture being removed with a knife. The rosette is moulded in a case-mould, B, in which are two pieces, B′ and B″, the batt being replaced by a cylindrical or conical mass of body, which is forced into the mould by pressure of the fingers; the two ends are then joined, and the interior circular part is smoothed by hand. The mould is emptied as before, by turning it, raising the case-mould B, and by drawing aside the two parts B′ and B″. The

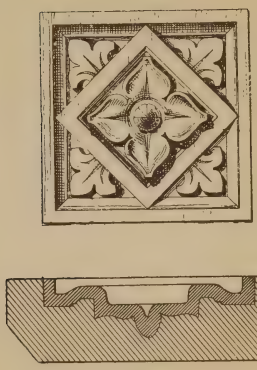


Fig. 75.—Panel and mould.

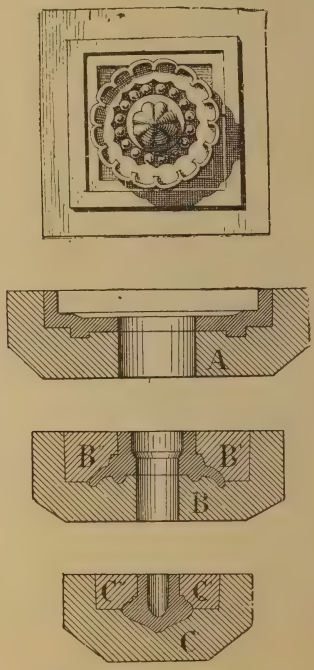


Fig. 76.—Moulding a panel.

central piece is moulded in the same way, in a mould consisting of three pieces, C, C′, and C″. The three parts of the panel are usually joined when the body is sufficiently hardened, but sometimes they are fired separately and joined together afterwards with cement.

A piece which is to be visible on every side, e.g. Fig. 77, is moulded in two or more parts which are afterwards joined. The grooved pedestal is first made, then each half of the body of the figure in separate moulds. A section on the line *mn* shows the arrangement of the mould, which consists of a case, A, in which is placed a series of pieces, *a*, *b*, *c*, *d*, etc., distributed in such a way as to allow of their ready removal. When the halves of the figure are sufficiently

dry they are joined first to each other and then to the pedestal by means of a little slip of the same composition. It is preferable to mould the tail by itself and afterwards to join it to the figure. When the articles are of very large dimensions, they are made in several pieces which are fired separately and afterwards joined together with cement.

Each model should be studied separately in order to determine the most suitable form of mould and the position of the joints, so as to allow the article to be removed readily from the mould without the risk of damaging delicate parts, such as the face in a statuette. It is necessary, also, to take into consideration the shrinkage during the drying, and the durability of the pottery in the kiln and in use.

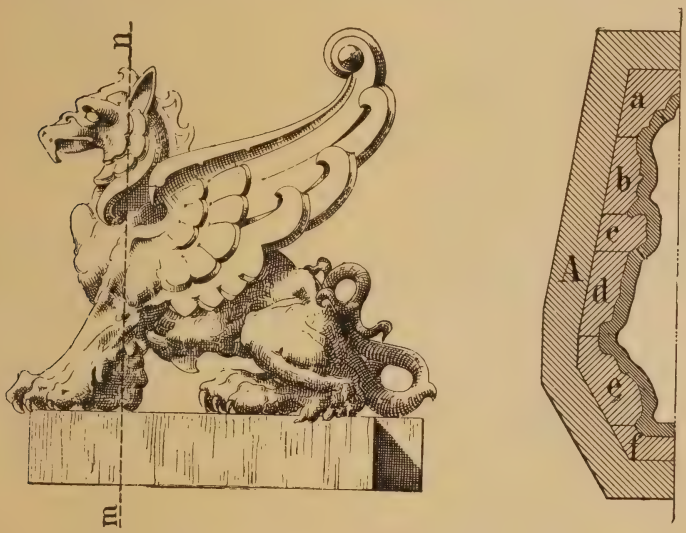


Fig. 77.—Model and part of the corresponding mould.

The making of moulds is generally entrusted to men who have been specially trained for this work.

Moulding, however simple it may be, requires a certain amount of technical skill for the uniform distribution of the body, without which certain parts may be more compressed than others, and these would crack during the drying and the firing. The moulds themselves, after having been used, should be dried, so as to remove the water which they have absorbed. This drying is often done either by aeration or in the same drying rooms as are used for the bodies, but it is better to use a specially designed drying stove. According to the shape of the moulds and the degree of consistency of the body, the moulds must be dried after each moulding, or, as is most frequently the case, after two or three fillings.

(*d*) *Moulding on a Jolley and Jigger.*

In moulding on a jolley or jigger—applicable to round or oval articles—the part of the piece which must be produced with the greatest amount of care (the interior or exterior as the case may be) is made on a mould placed on a jolley, while the other is made with a profile attached to a jigger. This kind of moulding is thus done by means of three tools—the jolley, the mould, and the jigger.

A *jolley* consists of a vertical shaft, similar to a potter's wheel, but the disc can be lighter and of less diameter. It is not necessary to modify the speed, and for articles of small dimensions (cups, plates, flower-pots, etc.) it is sufficient to have a jolley of constant speed provided with a brake well within reach of the operator.

The heads of jolleys which receive the moulds must be capable of being placed and removed very rapidly. For this purpose, they have at the top a truncated space corresponding to a similar projection on the mould. A simple pressure fixes and centres the latter (Fig. 78). The wheel-head may be of plaster, metal, or wood ; when it is of plaster, the edge of the truncated space is often strengthened by a lead ring.

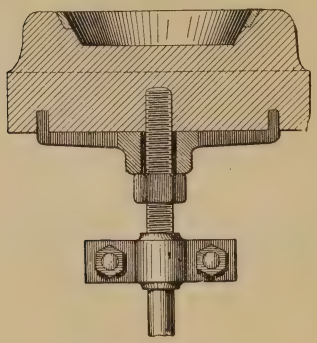


Fig. 78.—Jolley head.

Oval pieces can also be made on jolleys by using an arrangement such as that shown in Fig. 79, in which the jolley spindle ends in a metallic piece, in which slides a groove carrying at its centre the head and at its two ends some T's, the horizontal branches of which slide along an eccentric disc, fixed by means of iron pins on the table of the jolley. This eccentric imparts to the head a reciprocating movement which, in combination with the rotation of the jolley, causes it to describe an ellipse or oval, the form of which is determined by the amount of eccentricity.

The moulds are made of plaster and in one piece for all flat objects (dishes, plates, etc.) as well as for those wide at the top (cups), but it is necessary to make the moulds in two or three parts for articles with narrow apertures. In all cases they are terminated at the lower part by a truncated cone which fits into the head.

A *jigger* (Figs. 80, 81) is a device for carrying a profile in such a manner that it can be applied to the exterior or interior of the mould on the jolley as may be required. The jigger may be mounted on the same table or framework as the jolley, or it may be quite separate, according to convenience.

Jiggers are usually of two types :—

(*a*) Those consisting of an inclined arm and balance-weight, mounted on a pivot (Fig. 80), the end of the arm opposite the weight

being provided with a slot to which the profile is attached ; this slot is very important, as it permits the ready adjustment of the profile.

(*b*) Those consisting of an upright frame carrying two or more pulleys from which are suspended a vertical steel rod or counterpoise (Fig. 81). The rod passes through guides which ensure its accuracy of movement, and at its lower end is a device for attaching the profile.

When in use, a mould is placed on the jolley, a piece of body is

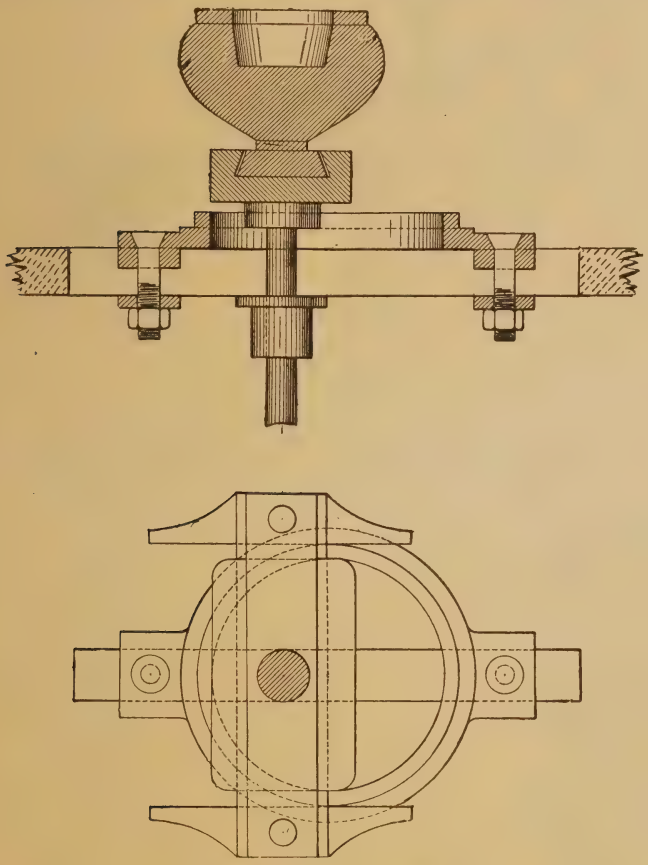


Fig. 79.—Oval jolley head.

laid in or on the mould, which is then rotated and by pulling down the handle of the jigger the profile compresses the body against the mould, shapes the body, and cuts off the surplus material.

Profiles (see Fig. 82) are rather thick sheets of steel or strongly fired body (fine earthenware or porcelain body) of such a shape so as to remove the excess of material and to press the body against the mould.

When moulding thin, flat articles, such as plates and dishes, it is advisable to make a " batt " on a separate machine in which the

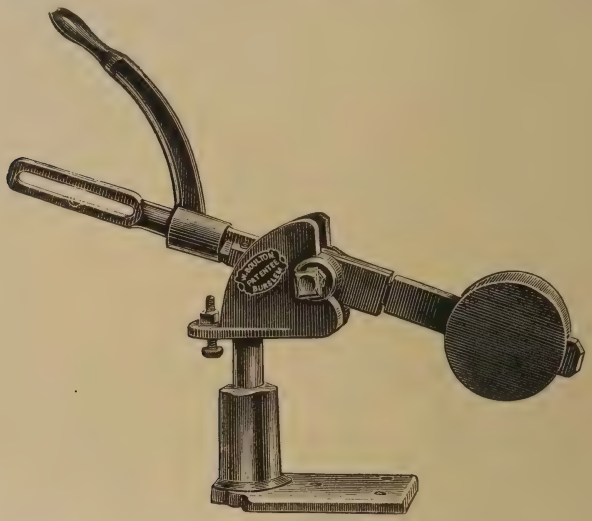


Fig. 80.—Jigger.

profile is replaced by a disc and the wheel-head by another disc (Fig. 82), so that a piece of body placed on the wheel-head is pressed

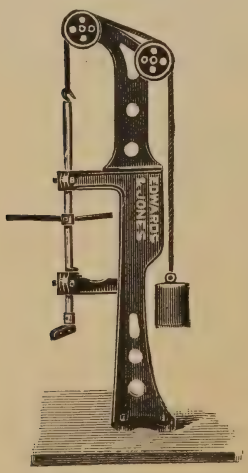


Fig. 81.—Upright jigger.

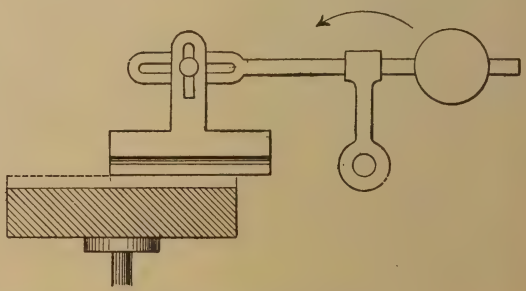


Fig. 82.—Batt-making.

into the form of " batt " by means of the upper disc. When the body is very lean (as porcelain body) it is sometimes necessary to use a wooden ring covered with a stretched skin, mounted on the

wheel-head and a helicoid profile on the jigger; the "batt" obtained is removed with the ring.

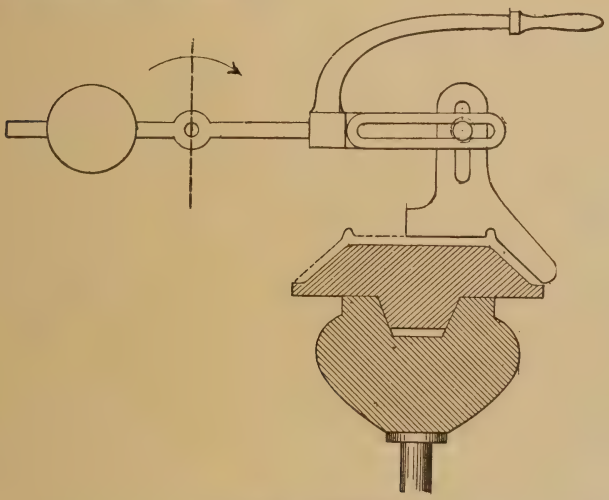


Fig. 83.—Jiggering.

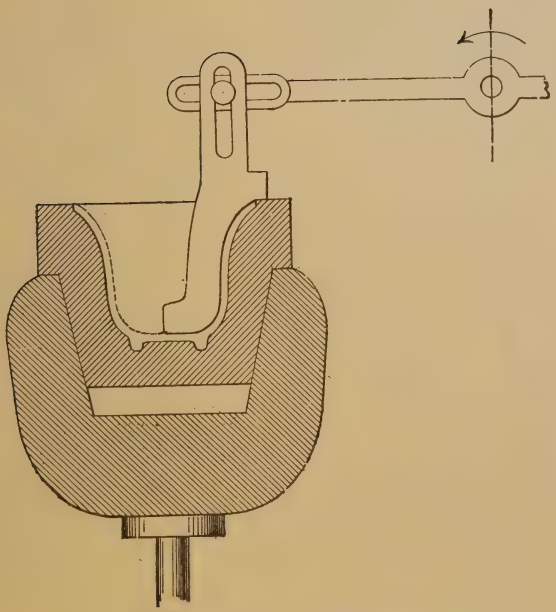


Fig. 84.—Jiggering hollow-ware.

Plates and similar articles are made outside the mould (Fig. 83), the "batt" being placed on or in the mould, the jolley being set

in motion and the body pressed close to the mould. The profile is then drawn down until the article is of the correct shape; Fig. 84 shows the moulding of a deep piece of pottery in a similar manner. The profile must be so placed that it leans to the centre of the piece so as to drive the excess of body towards the circumference.

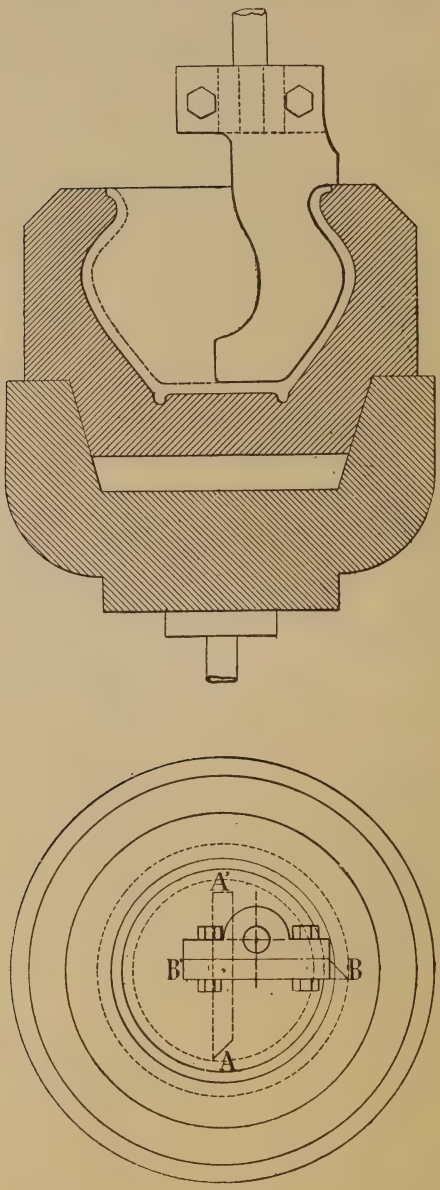


Fig. 85.—Making with adjustable profile.

For some pieces of pottery a rigidly mounted profile is inapplicable; Fig. 85 shows a better arrangement in which the profile can slide on a support so as to be either concentric or slightly eccentric to the axis of the jigger. When the profile is in the position AA′ it can enter the piece of ware, it is then made to take the position BB′, which puts it into contact with the body. To allow of emptying the mould must be in two parts.

The use of a profile also demands a fairly plastic body unless the piece is given a thickness considerably greater than is necessary in the finished ware, and, when dry, is turned to the requisite size and shape (p. 116). The turning then constitutes the chief operation in the making, and must not be confused with the operation of finishing, which is dealt with later.

(e) *Mechanical Moulding by Compression* (*Pressing*).

The machine used in this process consists of two essential parts—the mould (sometimes termed a *die* or *press-box*) and the press. The moulds, in spite of their diversity of shape, may be divided into two classes—squeezing moulds and compressing moulds.

Squeezing moulds consist of two parts, between which the mass of body is squeezed, and forced to take the desired form, the excess of body escaping between the two parts of the mould. This mode of making permits the use of bodies of almost any degree of consistency, provided that the article does not lose its shape on being taken out of the mould. When soft body is used, a plaster mould is preferable, or a metal mould covered with plaster in those parts in contact with the body, plaster being the material which allows of the easiest delivery. When the body is stiff, plaster would not resist the pressure which must be applied, and metal moulds are used; they must generally be lubricated in order to prevent sticking.

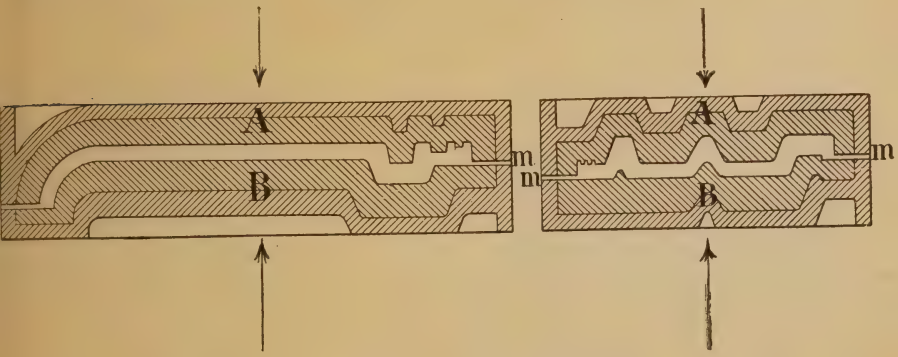


Fig. 86.—Moulds for pressing Marseilles tiles.

Fig. 86 represents the pressing of a tile in soft body by this process in metallic moulds lined with plaster. When the two parts of the mould rest on each other, the space between them corresponds exactly to the form of the tile. A "batt" or cake of body, about the same size as the tile, but slightly larger, is laid between the moulds. The excess of body escapes at *m*. The mould is emptied by removing the upper part and turning the lower one upside down.

For moulding a flower-pot in a body of medium plasticity, the metal mould consists of three parts—a mould, a core, and a movable bottom plate. A piece of clay paste of suitable size and consistency is placed in the mould, and by hand or mechanical power is pressed into shape by the core. The latter is then raised, and by raising the bottom plate delivery is effected. The force necessary for such moulding is that expended by the friction of the body sliding on itself and on the walls of the mould. This force depends on the consistency, on the quantity of body in excess, and on the form of the mould. In order to avoid deformation in delivery, the body must

not be too soft, but it is not desirable to make the body too stiff or too plastic, as this wastes power and gives a laminated structure. If any air remains imprisoned in the body it is compressed and prevents the body from conforming accurately to the shape of the mould ; this difficulty is lessened by giving two or even three successive pressures, removing the core or top die a little each time to allow the compressed air to escape. Air-holes may be pierced in the mould, but unless a very uniform body is used the latter have a tendency to become stopped up. Helical air-grooves in the core are much more satisfactory, particularly if the mould is rotated rapidly.

Compressing moulds consist of a box in which the body is placed and compressed by a plunger entering and fitting the mould exactly. This pressing is done with a stiff plastic, semi-dry, or dry body, the moulds being always of metal. They are sometimes made in several pieces in order to allow of easier delivery of the ware.

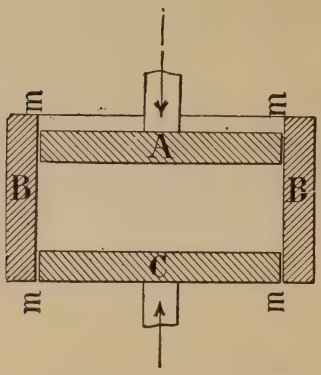


Fig. 87.—Die-box of press.

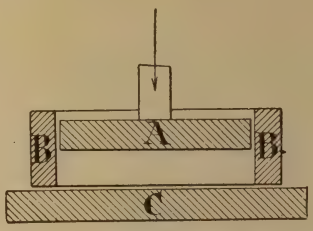


Fig. 88.—Die-box for encaustic press.

Fig. 87 represents the principal arrangements of this mode of shaping. A " batt " made of stiff plastic body, or a measured quantity of dry body, is placed in the mould formed by the parts B and C, then the plunger A is made to descend. When the pressure is sufficient, this plunger is raised, then the delivery is effected by raising the bottom plate C. In some machines the mandrel, A, and the bottom plate, C, approach each other simultaneously in order to increase the pressure.

In articles of slight thickness, such as tiles, the arrangement shown in Fig. 88 is often preferred, delivery being effected by removing part B from the mould.

The power needed to drive a press has first to force the body to fill the mould and afterwards to compress it to the desired extent.

In pressing there may be two objects :—

(1) To give an exact form to a soft plastic mass which has previously been roughly shaped, and then allow the body

to harden and the greater part of the shrinkage to take place.

(2) To make articles with a dry body in a single operation.

In the former, only the shape of the ware can be improved, and not its quality, for the compression tends to cause cracks in the body which are only imperfectly rejoined in consequence of their lack of plasticity.

In the second case, there must be a much more powerful compression, as the body is drier, and powdered materials do not flow readily under a slight pressure. But as pressure can never impart to the molecules of clay the cohesion which they acquire by their mixture with a sufficient quantity of water, and as the air between the grains of the dry body cannot entirely make its exit by the joints of the mould or by the air-holes which are arranged in it, dry moulding does not produce so strong an article before firing as does a plastic body. Fig. 88 shows that the force of compression begins by acting on the upper parts of the body, and spreads nearer and nearer to the lower. The air contained in the latter cannot traverse the upper layer, as this has already been rendered dense by compression ; it is, therefore, imprisoned in the form of flat bubbles, which may separate the lower layers of body and prevent adhesion. This serious defect can only be minimized by repeated pressings, allowing the imprisoned air to escape between each, but with very thick wares and bricks this remedy is often insufficient. Moulding with a dry body does not take into consideration the essential physical properties of the clay, and would never be used if it were not that the simplification of the preparation of the bodies and the suppression of the drying considerably reduces the cost of manufacture. This is usually done at the expense of the quality of the ware, though it is suitable for some bricks, tiles, electrical fittings and other small articles.

Presses are of numerous patterns, and a complete description would require a whole treatise. Presses can act either by shock (stamping) or by pressure (squeezing). In presses which operate by shock (sometimes termed *drop-presses*) the movement is perforce intermittent, the plunger or one of the parts of the mould continuing its movement until all the active force has been destroyed by resistance. With squeezing moulds, the plunger descends gradually, and the pressure increases in the same manner ; the stoppage is produced when the two parts of the mould come in contact, the blow being mitigated by the presence of the body. In all presses, the body alone determines the stoppage of the plunger, and it is therefore very important to have the same quantity of body in the press each time it is used or the articles will vary in thickness. Sometimes it is advantageous—particularly with hand-operated presses (Figs. 89 and 90)—to first apply a squeezing pressure, then to release it and deliver one or more blows to the material in the press. Thus, in working the screw-press shown in Fig. 90, the die or mould is filled and the wheel is turned rapidly so that the plunger descends

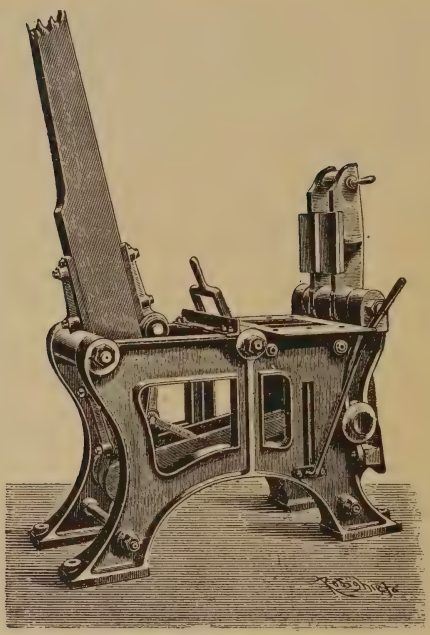


FIG. 89.—Lever press.

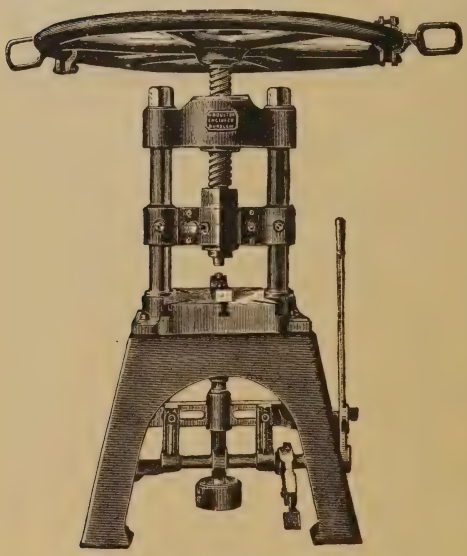


FIG. 90.—Screw-press.

and squeezes the material in the mould; the wheel is reversed about half a turn, and is then pulled round suddenly so that the plunger delivers a sharp blow, the effect of which is equivalent to a much greater pressure than can be applied by the slower movement of the wheel.

In the *lever-press*, shown in Fig. 89, the mould is filled, the cover (shown on the right) is lowered and held in position by a catch, and also by the large lever shown on the left. The pressure is applied by means of the lever, which is afterwards raised, the cover is also raised, and the finished article is lifted out of the mould by moving a lever (shown in front of the machine), which raises the bottom plate. In some lever-presses the lever acts on the bottom plate of the mould and applies an upward pressure.

In the screw-press (Fig. 90) the moulder turns a screw by the aid of a fly-wheel, provided with handles. The screw carries the upper part of a mould, the second half of which can slide backwards and forwards on the table of the press, and in some machines it can be turned upside down, or is fitted with a rising bottom plate to deliver the finished

article. The fly-wheel of the screw may be driven mechanically by means of two discs (Fig. 91), one causing the screw to rise and

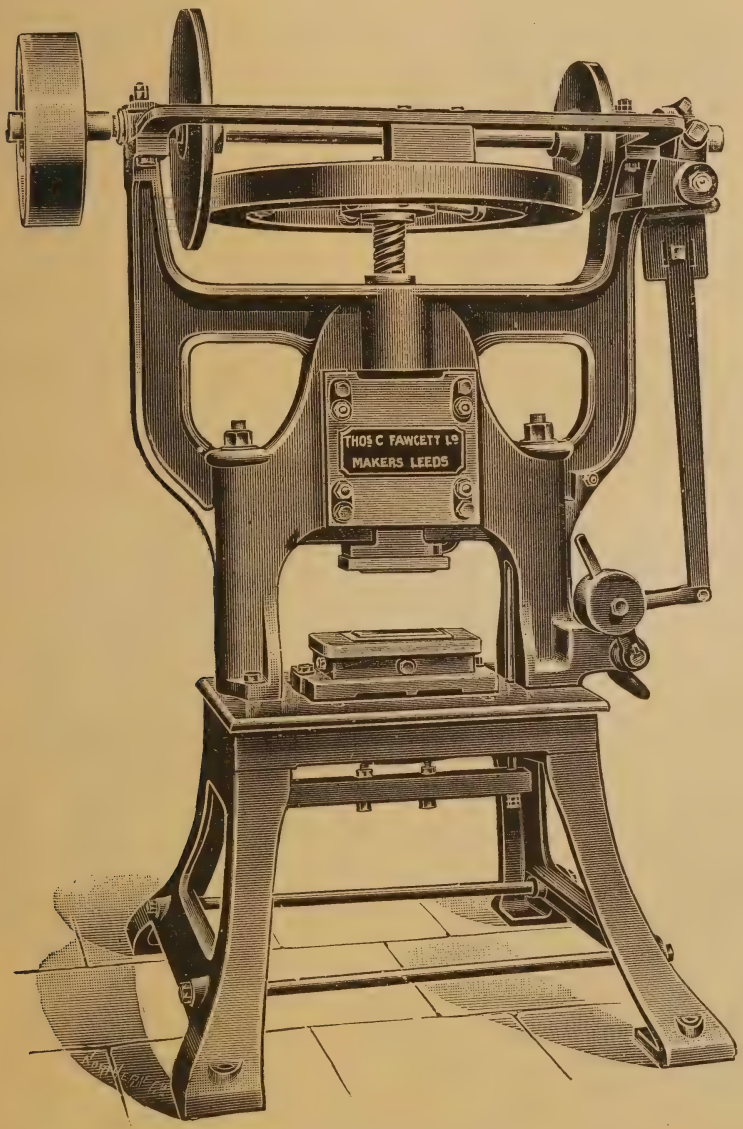


Fig. 91.—Power-driven screw-press.

the other to fall, each disc being brought in turn in contact with the fly-wheel. Presses are also used in which the upper end of the

plunger is attached eccentrically to a vertical disc or cam, the pressure being applied by the latter. In the eccentrically-driven roofing-tile press, shown in Fig. 92, the lower part of five moulds is placed on a drum which revolves intermittently so as to allow a fresh "batt" of body to be placed on one side of the machine and the finished tiles to be removed from the other. The upper part of the mould is attached to the plunger. This arrangement facilitates the delivery and feeding of the press, and enables 500 or more large (Marseilles) roofing tiles to be made per hour. Fig. 93 shows a brick-press with a rotary table, the pressure being supplied by an eccentric shown in the upper left-hand corner of the illustration. After pressing two bricks, the

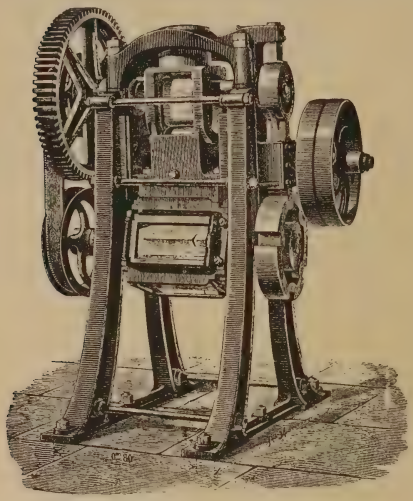


Fig. 92.—Revolving press for tiles.

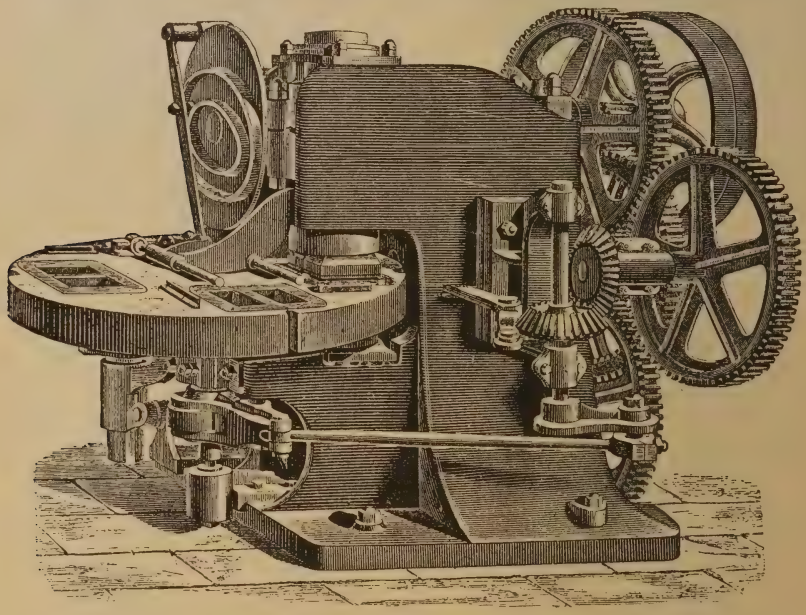


Fig. 93.—Brick-press with rotary table.

table turns slowly until the next pair of moulds comes beneath the plungers ; simultaneously, the bottom plate below the previously pressed brick is lifted so that the bricks can easily be removed.

Presses in which the plunger is jointed—forming a *toggle-lever*—are extensively used for making bricks and tiles from a semi-dry powder.

Large articles are sometimes made in presses operated by hydraulic pressure ; similar presses are also used for making tiles.

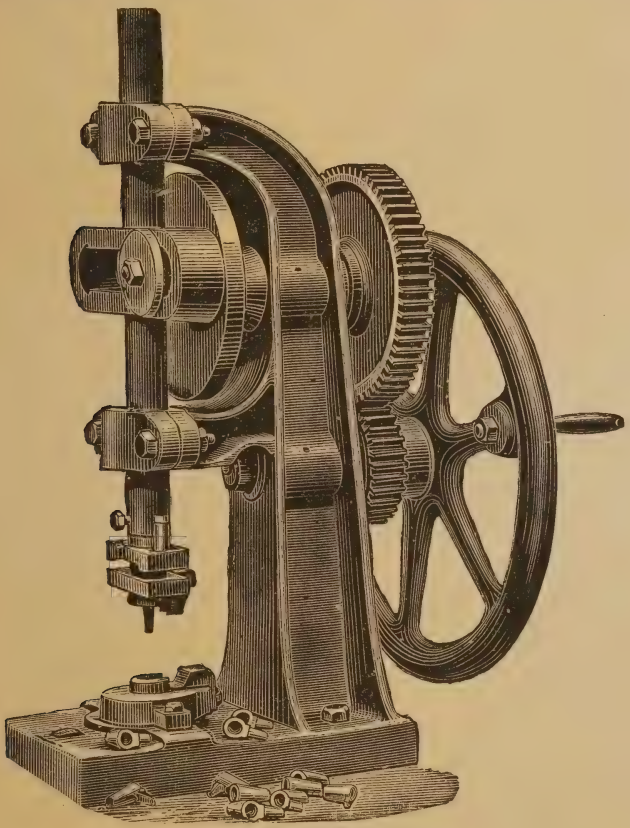


Fig. 94.—Press for small articles.

When very small articles have to be made the press may be worked by hand (Fig. 94), but generally they are power-driven.

(*f*) *Moulding by Slip-casting.*

If a dry plaster mould is filled with a liquid body or slip and the surplus liquid is poured out at the end of some minutes, the inside of the mould will be covered with a layer of the body, a part of the

water having been absorbed by the plaster. By leaving this body in the mould until it has become sufficiently hard it can be delivered, and an article obtained reproducing exactly the form of the mould, and of any desired thickness. The body used for slip-casting should not be very plastic, or the absorbing action of the plaster would be hindered, as the layer nearest the mould would form an impermeable coating. Hence, this process of making can only be employed for porcelain bodies or for others having china clay, fireclay, or other lean clays as their principal constituent. The body should be extremely fine and very carefully prepared. It is expedient to pass it through a very fine sieve before use, so as to separate all air-bubbles. The moulds are similar to those used for moulding by hand, and are in one or more pieces, according to the form of the article to be reproduced. The excess of slip may be removed either through the same orifice as that through which the mould was filled, or (which is better for large articles) through a lower one, which is closed by a plug during the filling. The length of time the mould remains filled with slip depends on the plasticity of the body, on the absorbing power of the plaster, i.e. on the thickness of the walls of the mould (2 to 4 inches), on its dryness, and on the thickness of the article to be produced. It is usually necessary to dry the mould after each filling. With thick-walled articles the "pouring" should be done in three or four portions, allowing the body to stiffen a little between each. When the moulds have complicated designs or are difficult to work, it is well to paint them with the body slip by means of a brush, before casting, to prevent any air-bubbles from adhering to the plaster. If the plaster absorbs too rapidly, which would cause the articles to break, the inside of the mould should be painted with a very thin layer of an emulsion of hard soap and olive oil.

The absorption of the plaster can be hastened by surrounding the mould with a hermetically sealed case, between which and the mould a vacuum is made by means of an air-pump, or by closing the interior of the mould and connecting it with a reservoir of air under pressure.

Moulding by casting greatly simplifies the preparation of bodies and allows the making of pieces which it is very difficult or even impossible to obtain by other processes. Unfortunately, it only applies to certain bodies, and necessitates a very large number of moulds, which rapidly wear away.

(*g*) *Finishing.*

Finishing consists of a series of manual operations, which vary according to the shape of the article made, but always have two purposes :—

(1) To correct any imperfections in the shaping of the articles ; and

(2) to unite the different portions of an article when these have been made separately.

The imperfections in shaping occur chiefly at the seams of the moulds, and in certain parts which had to be left solid, but which it is necessary to scoop out. Any defects in the surface of the mould will be reproduced in the articles, and may require to be "made good" in the finishing process.

The finishing is generally done by means of hand tools. When the articles have been thrown, the finishing is generally done on the lathe, the body being first allowed to harden slightly. When a large number of pieces is made simultaneously, certain precautions must be taken so that their drying takes place conveniently. When necessary, the drying is arrested by keeping the articles in a damp place.

The manual operations of finishing may be thus distinguished :—

Scraping—which consists in removing the marks of the seams and other defects in the moulds, and any excess of material.

Carving (*undercutting*)—in which all unnecessary parts are removed, including those which have been left solid in order to facilitate delivery from the mould.

Grooving and perforating—the aim of which is to make hollows or holes, which it would be too complicated or impossible to obtain directly in the moulding process.

Repairing—i.e. correcting, by means of a small quantity of slip, the defects, such as bubbles, cavities, and cracks, which have arisen during the moulding.

Sticking—i.e. reuniting the thick parts of an article ; an example of this has been mentioned when dealing with throwing (Fig. 53). It must be done when the body is sufficiently plastic and yet has sufficient resistance to retain its shape under a certain amount of pressure. The parts to be reunited are cut bevel-edged, as in Fig. 95. If the sticking must be done at a corner, a little of the body in the form of a small cylinder is added at the re-entering part, as shown in Fig. 95. The parts to be united are first moistened, then one hand is placed inside, the other outside, and pressure is exerted, the workman endeavouring, with his fingers, to mix intimately the bodies of both parts. When the shape of the article does not allow of the hand being introduced on one side, it is replaced by a damp sponge fixed to the end of a stick. When the joint is completed, it is smoothed with a sponge, and finally with a scraper or rubber.

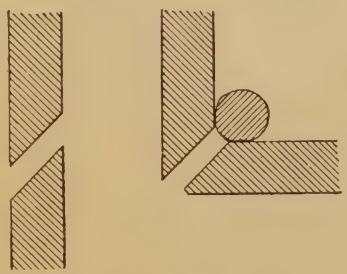


Fig. 95.—"Sticking."

Slipping is employed for joining parts of articles which are only slightly plastic, and for fine objects, handles, spouts, feet or stands, ornaments, etc., which have been made separately and would lose their shape by the comparatively rough treatment involved in sticking. The body must in this case be more consistent. The

parts to be united having been made and so adjusted that the surfaces correspond exactly with one another, they are rendered slightly rough by means of a small comb, are covered with a thick slip, and are pressed strongly one against the other. After a short time, the pressure may be released and the excess of body removed by means of a brush or knife. Fig. 96 shows the parts of a coffee-pot joined by slipping, the joined surfaces being indicated by the letters *m*—*m*. Sticking is a simple operation, but in order that it may be successful, the parts to be joined, as well as the slip, must have a suitable consistency. Experience alone enables the most favourable conditions to be determined.

The operation of slipping is known by the name of *handling*

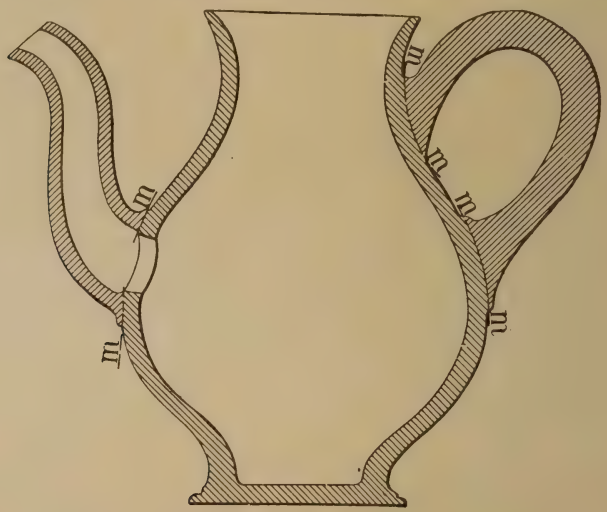


Fig. 96.—Fixing a handle and spout by "slipping."

when applied to handles, spouts, or stands, and by that of *sticking*, *sprigging*, or *figuring* when used for fixing ornamentation.

(*h*) *Slipping or Engobing.*

The term *slipping* or *engobing* is also applied to the process of covering an article with a layer of another body in the form of a slip in order (i) to modify the colouring and the appearance of the body of which the article is made ; (ii) to enable the article to be covered with a given glaze ; and (iii) to obtain decorative effects by the use of bodies, or engobes of various colours. The means employed for this purpose are mentioned in Chapter IX.

Slipping or engobing appears to be a very simple operation ; the chief difficulty consists in finding a slip which fulfils the required conditions and has the same shrinkage in drying and in firing as the body to which it is applied. The correct composition can only be ascertained by trial, a likely body being used as the foundation, and with this is mixed a plastic material, such as white clay, or a

non-plastic material, such as fine sand in various proportions, until the trial pieces obtained are without defects. If the body has more shrinkage than the slip, the latter cracks, leaving in its place the bare body. If the contrary defect (*peeling*) is produced, the slip becomes detached and breaks off in scales. It sometimes happens that the slip is more refractory than the body, and adheres badly after firing. This fault can be remedied by the addition of a certain proportion (from 1 to 10 per cent) of a *flux* or *frit*, which considerably increases the fusibility and the adhesion.

Prior to applying the slip, the article must be hard enough to be manipulated without danger of its losing its shape, but it must not be too dry to absorb the water in the slip, or the latter would dry without adhering.

The application of the slip or engobe may be made—

(1) By dipping the article in a vessel containing the slip, either by immersing it entirely or by only dipping those parts which it is desired to cover.

(2) By spraying or sprinkling the article with the slip, the excess of which falls into a vessel placed below—a process employed when it is only desired to cover the exterior of an article which it is not desired to dip.

(3) By filling the article with the slip, and by emptying it shortly afterwards—a method utilized for covering the inside of vessels ; it is sometimes termed *rinsing* or *washing*.

(4) By applying the slip with a brush.

In some cases it is necessary to have a slip of greater thickness than that which it is possible to obtain by the means just indicated, as in the case of paving tiles, which are liable to wear thin, and would leave the lower body with its natural colouring, or when the pieces of pottery have projecting parts, for which it is desired to preserve a precise form.

It is then necessary to have recourse to a process known as *incrustation*, which consists in moulding simultaneously two bodies which are afterwards placed one above the other, the thinner forming the *facing*, and the thicker serving to give to the article the thickness necessary for its solidity and representing the body proper. According to the process of making employed, incrustation can be done in different ways :—

(1) In *hand moulding*, the layer of fine body is placed in the mould in such a way that it fills all the parts to be in relief, the body then is placed in the mould, and forced to adhere to the other by judicious beating and pressure.

(2) In *pressing* a rough block is first made by means of two layers of the two bodies ; or, when the shaping is done with dry body, a certain quantity of powdered engobe is placed in the mould, and the filling is completed with powdered body. In both cases the pressure determines the adhesion of the body and its covering.

Further notes on coloured slips used in decoration are given in Chapter IX.

CHAPTER VI.

DRYING.

1. Drying Bodies.

Theory of Drying.—By the term "drying" is understood the operation by which the water of formation (which is needed in order that the articles may be made by plastic or allied processes) is removed so as to harden the articles sufficiently to enable them to be carried to the oven and placed therein, and to make the firing more rapid and less risky. When articles are made of dry body, the drying may usually be omitted and the ware placed in the oven immediately after it has been made.

In drying any "body," the surfaces first lose a certain proportion of water, which is replaced by that carried to the surface from the interior, this transference being continued till the centre of the mass is dry. There is thus produced a capillary flow of water from the centre towards the surface, the speed of flow depending on the texture of the body; it continues at the same speed so long as the centre of the ware is moist; then the speed diminishes, but does not cease for some time, viz. until the body is uniformly dry.

The elimination of the water takes place (theoretically) in two periods: in the first, its speed is constant and proportional to the duration of the drying; in the second it diminishes progressively until it ceases entirely. So long as there remains in the body a sufficient quantity of water to allow the particles of solid matter to be displaced, the latter collect together, filling up the spaces occasioned by the departure of the water which separated them. The result is a reduction in volume roughly equal to the volume of water removed. When there is no longer sufficient water between the solid particles to allow them to move, a further elimination of the water from the interior of the body produces spaces, *pores*, or *voids* equal to the volume of water which has been removed. This second phase of the drying continues until the whole water of formation has been eliminated. If the drying has taken place equally throughout the whole mass, these two phases would be clearly distinct, but this condition being impossible to fulfil, the edges and the surfaces being necessarily dry before the centre, the drying is in reality subdivided into three phases:—

(1) In which the body shrinks in volume proportionally to the water eliminated; (2) in which spaces or *pores* begin to form at

the same time as the body continues to contract ; (3) in which the shrinkage ceases, the pore-spaces produced being proportional to the water eliminated.

The following table shows the result of experiments on a plastic clay made by hand into cylinders 1·57 in. diameter and 7·87 in. long, the consistency being that of an ordinary plastic body :—

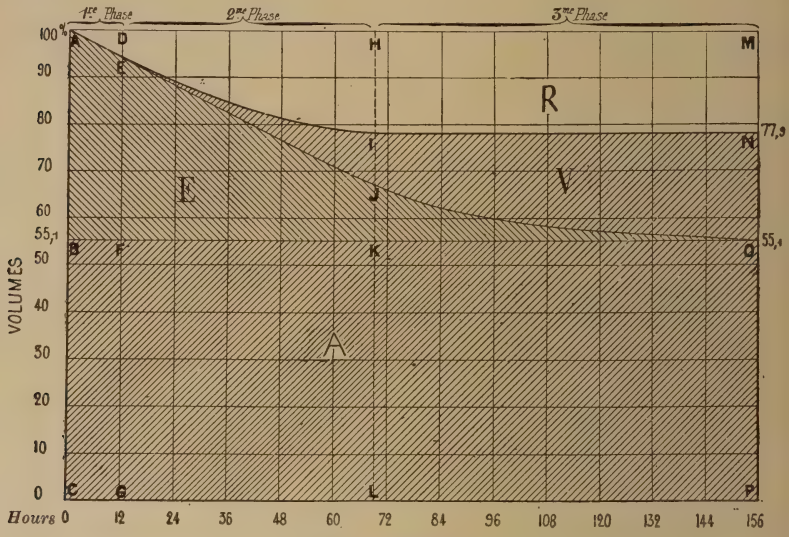
Duration of Drying in Hours.	Weight of		Lineal Shrinkage (Measured).	Volume of			Total Volume.
	Clay.	Water.		Clay.	Water.	Pore-Spaces.	
	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	
2	75	25·0	2·1	55·1	44·9	—	100·0
12	75	21·5	3·7	55·1	38·7	—	93·8
24	75	18·0	5·1	55·1	32·4	1·8	89·3
36	75	14·5	6·5	55·1	26·1	3·3	84·5
48	75	11·2	7·6	55·1	20·2	6·4	81·7
60	75	8·0	8·0	55·1	14·4	9·4	78·9
72	75	5·6	8·0	55·1	10·1	12·7	77·9
84	75	3·8	8·0	55·1	6·8	16·0	77·9
96	75	2·5	8·0	55·1	4·5	18·3	77·9
108	75	1·7	8·0	55·1	3·1	19·7	77·9
120	75	1·1	8·0	55·1	2·0	20·8	77·9
132	75	0·7	8·0	55·1	1·3	21·5	77·9
144	75	0·3	8·0	55·1	0·5	22·3	77·9
156	75	—	8·0	55·1	—	22·8	77·9

In this case the body, which had by weight 75 per cent of clay and 25 per cent of water, and by volume 55·1 per cent of clay and 44·9 per cent of water, after drying for 156 hours had a lineal shrinkage of 8 per cent, its volume being reduced to 77·9, consisting of 55·2 per cent of clay and 22·8 per cent of pore-spaces.

These figures can be represented graphically (Fig. 97) in which the perpendicular lines indicate the number of hours and the horizontal ones the volumes of clay, water, pore-spaces, and shrinkage. In the first stage of drying, lasting about twelve hours, the initial volume of the trial piece, represented by AC (of which AB stands for the water and BC for the clay) is reduced to EG, of which EF stands for water, the shrinkage DE being equal to the volume of water eliminated. In the second stage (from the twelfth to the sixty-ninth hour) the volume is reduced from EG to IL, the water is reduced from EF to JK, and the pore-spaces, at first nothing, become equal to IJ. Finally, in the third stage, from the sixty-ninth hour to the one hundred and fifty-sixth hour, the volume no longer varies, IL being equal to NP, owing to the fact that pore-spaces are formed in the place of the water, which latter is eliminated with increasing slowness.

The preceding table, as well as the graphic representation of it (Fig. 97), only refer to a single plastic clay, moulded by hand into

the form of cylinders, which were dried slowly and regularly; different figures will be obtained with other clays and under different conditions of drying.



R = Shrinkage. E = Water. V = Pores. A = Clay.

FIG. 97.—Drying chart.

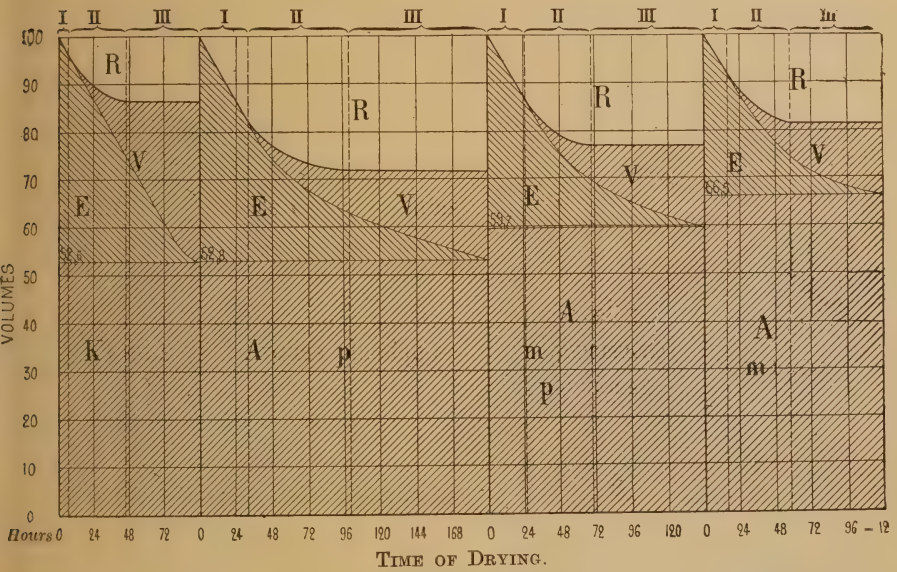
Influence of the Nature of the Body.—The following table shows the results of a large number of trials made with various clays, by measuring the duration of the drying and the shrinkage of the clay.

	Duration of Drying (hrs.).	Weight of		General Shrinkage.	Volume of the			Total Volume.	Proportion of Spaces.
		Clay.	Water.		Clay.	Water.	Pores.		
China clays { Plastic body	—	72·7	27·3	—	52·6	47·4	—	100·0	—
China clays { Dry body	93	72·7	—	4·75	52·6	—	33·8	86·4	39·0
Plastic { Plastic body	—	72·9	27·1	—	52·8	47·2	—	100·0	—
Plastic { Dry body	180	72·9	—	10·50	52·8	—	18·8	71·6	26·3
Modly. plastic { Plastic body	—	78·4	21·6	—	59·7	40·3	—	100·0	—
Modly. plastic { Dry body	144	78·4	—	8·30	54·7	—	17·3	77·0	22·5
Open { Plastic body	—	3·2	16·8	—	66·5	33·5	—	100·0	—
Open { Dry body	120	83·2	—	6·80	66·5	—	14·5	81·0	17·9

Clays were divided into four classes: china clays (average of seven different tests), plastic clays (six tests), clays moderately plastic (fifteen tests), and lean clays (nine tests). The body, being of

ordinary plastic consistency, was made into cylinders 1·57 in. in diameter and 7·87 in. long, which were dried simultaneously.

The preceding figures are represented graphically by Fig. 98. They show the differences between china clays and plastic clays. The proportion of water of formation is the same, but the china clays dry more rapidly, shrink less, and have, in consequence, a much larger proportion of pore-spaces. The more plastic clays show no differences, except those which result from the variable proportion of the water of formation. The preceding results being averages, certain clays can differ from them considerably, but in



R = Shrinkage. V = Pores. E = Water. K = Kaolins. A p = Plastic clays. A m p = Highly plastic clays. A m = Lean clays.

FIG. 98.—Drying chart.

these cases an examination of their composition will reveal the cause of their divergencies.

The greater the amount of water in a body, the longer is the time taken in drying, the greater the shrinkage, and the greater the amount of pore-spaces. It is well to remember that the proportion of the water of formation depends on the texture of the body, that is to say, on the fineness of its grains. As the grains of true clay are by far the smallest, these necessitate the most water ; then come those of calcium carbonate, next silica (sand, quartz, flint, etc., finely ground), and finally, those of coarse-grained silica. Thus, given equality of plasticity, a pure clay opened with limestone will absorb considerably more water of formation than the same clay opened with coarse silica.

Influence of Consistency on Drying.—By modifying the consistency of a particular body, the duration of drying, the shrinkage, and the proportion of spaces will vary at the same time. The firmer the body the more rapid will be the drying ; the greater the shrinkage and the fewer the pore-spaces—but there is no fixed ratio between these different quantities. For example, if it is desired to use a moderately plastic clay body, containing 5 per cent of hygrometric water, to make cylinders having a volume after drying of 100, it will be necessary to give to these cylinders when in the moist state a volume of—

100	for	5	per cent	of water.
104	„	10	„	„
111	„	15	„	„
120	„	20	„	„
130	„	25	„	„
141	„	30	„	„

That is to say, the shrinkage in volume will be—

0	per cent	for	5	per cent	of water,	or a lineal shrinkage of about			0	per cent.
4	„	„	10	„	„	„	„	„	1	„
11	„	„	15	„	„	„	„	„	4	„
20	„	„	20	„	„	„	„	„	7	„
30	„	„	25	„	„	„	„	„	10	„
41	„	„	30	„	„	„	„	„	14	„

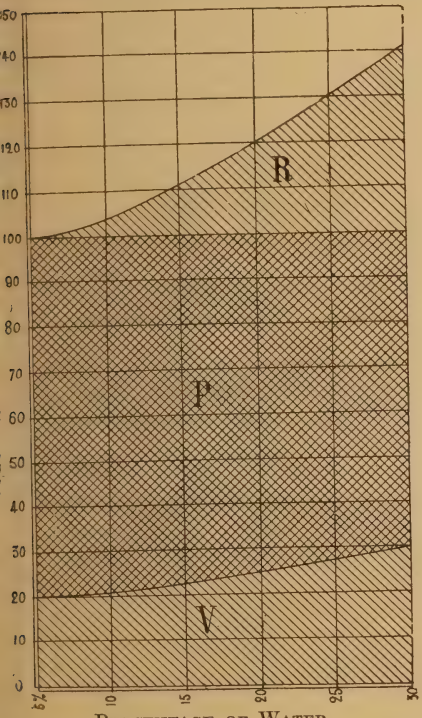
In Fig. 99 these figures have been represented in graphic form, but it must be understood that they depend on the nature of the body, on the method of formation, on the shape of the object, and, to a certain extent, on the rapidity of the drying, and must not be considered absolute, but only as in keeping with the general law which they represent.

The duration of the drying is influenced by the proportion of the water of formation. By making similar trial-pieces with bodies containing more or less water, by drying them together slowly, and by weighing them at regular intervals, it can be proved that about three-quarters of the water is evaporated during a time which is roughly proportional to the water content, but that in the later stages the drying becomes slower in proportion as the body becomes more consistent. Fig. 100 represents graphically the influence of consistency on the drying of the body previously mentioned.

Theoretically, the different methods of formation have no other influence on the drying than that which results from the variations in the consistency of bodies. Exception must, however, be made for certain defects of making which are due to inequality of pressure. These are fairly frequent in moulding by hand, and in throwing, when the workman does not exercise a very regular pressure with his hands ; in pressing, they may be due to a defect in the mould. In all cases, the parts most pressed dry slowest, and the inequality in the shrinkage may cause deformation of the ware.

Influence on the Shape of the Articles.—As evaporation chiefly takes place at the surfaces, the speed of drying will be proportional

to the area of the surfaces with reference to the volume. Thus, a solid brick of $9 \times 4\frac{1}{4} \times 2\frac{1}{2}$ in. has a surface of 143 sq. in. and a volume of 96 cub. in., while a hollow brick of the same dimensions having six hollow chambers with the intervening "walls" $\frac{1}{2}$ in. thick, will have a surface of 292 in. and a volume of 39 cub. in. The proportion of the volume to the surface is, in the first case, 1 to 1·48, and in the second 1 to 7·5. The drying will, therefore, be five times as rapid in the hollow brick as in the solid one.



R = Shrinkage. P = Clay. V = Pores.

Fig. 99.—Chart showing influence of consistency on shrinkage and pores.

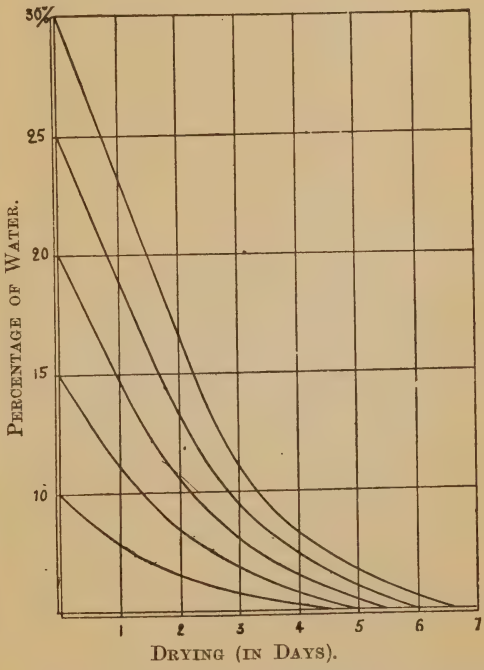


Fig. 100.—Influence of consistency on drying.

The general principle can be enunciated that the time of drying is proportional to the thickness, or to the ratio of the surface to the volume for all wares having a uniform but relatively slight thickness, such as hollow bricks, quarries, tiles, and thin pieces of pottery ware; but not for very thick articles, as the capillary movement of the water becomes slower and slower as the thickness increases, and it is difficult to remove the last traces of water from thick solid articles such as large blocks.

When the body is homogeneous the shrinkage should take place

uniformly in all directions, all dimensions diminishing in the same proportion if the shrinkage is not impeded by the shape of the article. The thin parts, such as the corners and edges, dry more rapidly, their shrinkages being hindered by the resistance of the thicker parts, which are still moist. When the latter dry, they are, in their turn, restrained in their shrinkage by the thin parts, which are already rigid. The result is a liability to warping and tension which often causes rupture.

It is well to observe the following rules in making articles of plastic materials :—

(1) Avoid too thick parts, by hollowing out where possible, so that every part of an article may have a uniform thickness. If it is impossible to fulfil this condition, an abrupt passage from one thickness to another should be avoided.

(2) Avoid unsymmetrical shapes or parts which project much. In some cases it is better to make the article in two or more pieces.

(3) Avoid articles of too large dimensions, especially when one portion is larger than another. It is better, as in the previous case, to make them in several pieces.

The rules as to shrinkage being uniform, seldom applies to large pieces or those of complicated shapes, and it is usually necessary, when the measurements of the articles must be accurate, to adjust the mould or die so as to correct any irregularities observed.

Influence of the Rapidity of the Drying.—When the drying takes place slowly and regularly, the inequality between the moisture at the edges, the surfaces, and the narrow parts and that of the interior or thicker parts remains slight, so that the variations in shrinkage do not have troublesome consequences, but when the drying is very rapid the antagonism between the parts already dry and those which are still moist can become sufficiently great to distort or even to break the ware.

The rapidity with which the drying can take place depends on the shape of the article and on the texture of its body. With reference to the shape, see page 150 ; as to the body, it must be neither so plastic as to cause distortion nor so open that the lack of cohesion will cause rupture.

Articles having narrow parts which dry too rapidly should be partially covered with damp cloths, or the thin parts may be roughly shaped and more accurately finished when the drying is sufficiently advanced for no further shrinkage to take place.

Theoretically, the speed of drying is great in the first period, is reduced progressively in the second, and becomes obliterated in the third, so that it must usually be restrained at the beginning of the operation, but from the time when the body, having lost its plasticity, has no further shrinkage, the drying can, without risk, be forced to take place more rapidly. In practice, the critical moment is easily recognized by the change of colour in the body, which becomes lighter. The shrinkage is slightly less when the drying is rapid than when it is slow. Thus, if two pieces of identical shape are

made of the same body, one being dried in twenty-four hours, having a shrinkage of (say) 7·75 per cent, and the other, the drying of which occupied fifteen days, will probably have a shrinkage of 8·50 per cent.

2. Processes of Drying.

In order to dry a body it must be placed in a relatively dry atmosphere which can provide it with a sufficient quantity of heat to ensure the conversion of all the water present into vapour. This does not mean that the water must be converted into steam (i.e. into water at a temperature of 100° C., or above), because air which is not saturated with moisture will, without any further heating, absorb water from any moist article until the air is saturated at that temperature. If the temperature of the air is raised by heating it artificially it will be able to absorb a further quantity of water until it is saturated at the higher temperature attained by it. Hence, in drying bricks, tiles, pottery, and other ceramic articles the drying may be effected :—

(i) By means of a large quantity of air without any artificial heat, this air being supplied in relatively small quantities, which are frequently renewed by a process of ventilation.

(ii) By a comparatively small volume of air which is slowly heated to a high temperature.

(iii) By a moderate quantity of air at a moderate temperature.

The choice of one or other of these methods should depend on the nature of the articles to be dried.

It is possible to determine, independently of the process of drying employed, the volume V of air and the amount of heat C necessary to evaporate 1 kilogramme of water contained in a body having n per cent of water of formation.

Let θ be the temperature of the surrounding atmosphere ; T the temperature of air entering into the dryer ; t the temperature of air going out of the dryer ; p the weight of water vapour in grammes contained in 1 cubic metre of air entering ; P the weight of water vapour in grammes contained in 1 cubic metre of air leaving the dryer ; a the coefficient of expansion of gas = 0·00366 ; 1·3 kilo is the weight of a cubic metre of air at 0° Centigrade ; 0·237 is the specific heat of the air ; and 0·200 is the specific heat of the body.

The volume of air necessary to evaporate 1 kilogramme of water is

$$V = \frac{1000}{(P - p)\,\frac{1 + aT}{1 + at}}$$

And

$$\frac{0{\cdot}308V(T - t)}{1 + at} = 606{\cdot}5 - 0{\cdot}695t + 0{\cdot}2n(t - \theta) \qquad (b)$$

On the other hand, if the air passing out of the dryer is saturated with moisture, t and P are connected by a function given in suitable

tables, indicating the tension of the water vapour in the air at the different temperatures ; p can be considered as a known quantity, that is, at the maximum, the weight of water vapour contained in 1 cubic metre of air at $\theta°$. There are, therefore, three unknowns : V, T, and t, connected by two equations, (a) and (b), which, in leaving the problem indeterminate, allows the choice of the most suitable values for either T or t.

The quantity of heat, C, expended is equal to the number of calories necessary to raise the temperature of the volume of air from θ to T, and is therefore

$$C = \frac{308(T - \theta)}{P(1 + at) - p(1 + aT)} \qquad (c)$$

These formulæ are not very easy of application ; it is better in practice, to take the following table as a basis :—

Temperature.	Maximum Tension of Water Vapour.	Maximum Weight of Vapour contained in 1 cb. m. of Air.	Heat Absorbed by 1 cb. m. of Dry Air, the Temperature of which is raised by 1°.	Heat Absorbed by the Volatization of 1 kg. of Water.	Water Evaporated by 1 cb. m. of Dry Air, the Temperature of which is lowered by 1°.
Degrees.	Mm. of Mercury.	Grammes. P.	Calories. C.	Calories.	Grammes. E.
0	4·5	4·8	—	607·0	—
5	6·5	6·7	0·303	608·5	0·498
10	9·1	9·3	0·297	610·0	0·487
15	12·7	12·7	0·292	611·5	0·477
20	17·4	17·1	0·287	613·0	0·468
25	23·6	22·8	0·282	614·5	0·459
30	31·6	30·1	0·278	616·0	0·451
40	55·0	50·9	0·269	619·0	0·434
50	92·0	82·3	0·261	622·0	0·418
60	148·5	129·1	0·253	625·0	0·404
70	232·6	195·3	0·245	628·0	0·391
80	353·9	290·2	0·238	631·0	0·378
90	527·0	412·7	0·231	634·0	0·365
100	760·0	589·5	0·226	637·0	0·355

The volume V is easily found by the formula

$$V = \frac{1000}{E(T - t)} \qquad (1)$$

in which E is the weight, in grammes, of the water evaporated by 1 cubic metre of air at an average temperature $\frac{T + t}{2}$. It should be observed that $p + E(T - t)$, that is to say, the weight of water removed by 1 cubic metre must be lower than, or at most equal to, the value of P corresponding to the temperature t, so that

$$E(T - t) \leqslant P - p \qquad (2)$$

The heat C, furnished by 1 cubic metre of air, the temperature of which is raised by 1°, is given by

$$C = V(T - \theta)c,$$

in which c is the value corresponding to the temperature $\frac{T + \theta}{2}$ or

$$C = \frac{1000\,(T - \theta)c}{E(T - t)} \quad . \quad . \quad . \quad . \quad (3)$$

In order to apply these formulæ to an existing dryer, it is necessary to measure the temperatures θ, T and t, and the contents of water vapour P and p. But these determinations do not give any information on the variations which can be produced in the interior of the dryer. For the latter, a small apparatus, shown in Fig. 101, called an *evaporimeter*, may be used. It consists of a glass tube graduated in millimetres, closed at the top by a ring, by which it can be suspended, and at the lower end by a sheet of blotting-paper, of which the area is known, held by means of a small spring. The tube is filled with water, closed with the blotting-paper, and hung up in the dryer. At the end of a suitable time, the volume of the water evaporated is read off on the graduations; it has no signification of absolute value, but by comparison with the figures given on other occasions by the same tube, is proportional to the intensity of the drying in the part of the dryer in which the instrument has been placed.

Fig. 101.—Evaporimeter.

Aeration is the term used to designate the drying of articles in the open air or in open sheds in which no artificial heat is used. The heat necessary for the evaporation is furnished by the atmosphere; the renewal of the air is caused by the action of the wind and by the difference of weight between the exterior air and the denser air in the dryer.

In aeration, there can be no drying when the atmosphere is saturated with water vapour, which is frequently the case in time of rain or fog. In order that the drying may be brisk, the temperature and the velocity of the wind must not be too low. A dry, fresh wind is better than a greater heat with less displacement of the air.

It is well, in the construction of aeration-dryers, to avoid low, sheltered places, and to choose a well-aired site. The drying is twice as rapid at a height of 3 ft. as on the ground itself, and trebly so at a height of 6 ft. 6 in., so that elevated dryers are advantageous. It is also necessary to avoid crowding or the placing of one dryer too near to the others. They should be arranged in such a way

that the wind may easily pass through them, should present their largest surface in the direction of the most frequent dry winds, and must be well drained. The ware must be protected from the rain even when it is driven sideways by the wind. Too brisk a circulation of air must be avoided, and movable screens, which diminish the force of the wind and prevent the rays of the sun from striking directly on the ware, should be used.

Except for the manufacture of common bricks, which are simply piled on top of each other, the ware is generally arranged on isolated wooden stages (Fig. 102) or grouped together in some structure (Fig. 102A). The pieces of ware are sometimes placed direct on shelves, but usually each of them is supported by a plank or wooden frame, the form and dimensions of which depend on those of the articles.

In Western Europe, aeration can only take place during five to eight months of the year, and drying almost ceases during the cold and wet months. If the exterior temperature falls to 2° C. or 3° C. below zero, the water contained in the ware freezes, and the increase in its volume (as ice) breaks the articles, which fall to pieces or crack at the time of thaw. This destructive action of the frost is not produced on dry articles, i.e. those which contain no water of formation.

The volume of dry air theoretically necessary to evaporate by aeration 1 kilogramme (2·20 lb.) of water is

$$V = \frac{E(\theta - t)}{1000}$$

with condition 2 (p. 154), $E(\theta - t) \leqslant P - p$.

In damp climates, the water vapour contained in the air averages $\frac{2}{3}$ of the maximum weight which it can contain. It is reduced to half the maximum in dry climates. In Europe, the average temperature during the seasons in which aeration is possible varies from 8° C. to 25° C.

For an outside temperature of 10° C., V = about 100 cub. m. per kg. or 62 cub. yd. per lb., and for a temperature of 25° C., V = about 43 cub. m. per kg., or 27 cub. yd. per lb.

These figures may appear large, but it must be noted that a scarcely perceptible wind of $6\frac{1}{2}$ ft. a second is sufficient to send through an aperture of 1 sq. in. a volume of 6 cub. yd. per hour.

In spite of its many inconveniences, aeration is much used for the drying of heavy wares containing a large quantity of water, such as bricks, the product of filter presses, etc., because, beyond the expenses of installation, the only cost is for the necessary manual work of moving the ware and placing it on the shelves. The high cost of labour at the present time sometimes makes the cost of drying by artificial heat cheaper than drying by aeration, because the fuel costs less than the labour required for handling bricks in open sheds or hacks.

Fig. 102.—Shed dryer.

Fig. 102A.—Section and part plan of shed dryer.

Heating.—The heat expended in evaporating 1 kilogramme (2·20 lb.) of water is given in formula 3 (p. 155), namely—

$$C = \frac{1000(T - \theta)c.}{E(T - t)}.$$

If the outside temperature $\theta = 0$, this relation is reduced to

$$C = \frac{1000(Tc)}{E(T - t)}.$$

This heat is least when $E(T - t)$ is greatest, that is to say, when this product is equal to $P - p$ (formula 2). In other words, the heat expended for the evaporation is least when the air goes out saturated with water vapour. This is shown in the following table :—

Temperature of the Air entering into the Dryer.	Minimum Temperature of the Air going out from the Dryer.	Number of Calories Expended to Evaporate 1 kg. of Water (2·20 lb.).
Degrees C	Degrees C.	
20	11	1360
40	18	1120
60	24	1030
80	28	960
100	31	930

The figures in the above table are the minimum, and must be increased from 50 to 100 per cent, according to the circumstances, in order to show the real expenditure, in calories. They show that it is desirable to heat the air entering into a dryer as much as possible on condition that it always goes out nearly saturated with water vapour.

It is seldom that a dryer can be heated directly with the gases proceeding from a fire, as they are too hot, and leave deposits of soot and other substances, and occasion condensation of sulphurous vapours, which are always injurious, on the ware.

The air may, however, be heated in two ways : either the heat is produced in the interior of the dryer, as when pipes or a hot floor is used, or the air is heated before it enters the dryer. Sometimes a combination of both methods is used. In both cases, it is sought to utilize as much as possible of the heat which has been lost from the kilns or from the waste steam of non-condensing engines.

Ventilation is often produced by simple aeration, the heated air entering and departing from the dryers by openings more or less regulated, or sometimes simply by fissures in the partitions and in the roofing. This system is only permissible when there is a large

amount of waste heat available or the drying is done in buildings. In modern plants it is usual to employ a special process of ventilation, e.g. chimneys or fans.

In a *chimney*, the air must pass out at a higher temperature than that of the atmosphere. Its velocity is given by the following formula :—

$$v = \frac{\sqrt{2ga\mathrm{H}(t - \theta)(1 - a)}}{1 + at}$$

in which $g = 9{\cdot}8088$; $a = 0{\cdot}00366$; H is the height of the chimney ; t, the temperature of the air at the exit end of the dryer ; θ, that of the outside air ; a, the relation of the resistance opposed to the current of air by all the obstacles which it meets on its way to the base of the chimney.

The factor $(1 - a)$ is to allow for the difference between the calculated and actual velocity ; i.e. the losses due to friction and to turns in the flues.

If the flues are not long, the resistance slight and the section S is large enough, good ventilation can be obtained with chimneys from 25 ft. to 50 ft. high, for a difference of temperatures $(t - \theta)$ of only 3° to 4° C. As the temperature t is never very high, dryer chimneys are often made of wood covered with tar to preserve them from the weather.

Fig. 103.—Fan.

Fans must be used when a current of air meets with a great resistance in its course. Their disadvantage is the necessity of motive power, but they have the advantage of ensuring a powerful draught which can be regulated at will, independently of the weather, so that they are being increasingly used. They are all based on the same general principle, though the shape of the fans (Fig. 103) varies according to the makers. In the arrangement generally adopted, a pulley drives the shaft carrying the fan, which is supported by special bearings. The structure is placed in any position, vertical, horizontal, or inclined, against a circular aperture in the wall. The diameter of the hole is equal to that of the fan. The latter draws in the air and forces it through the aperture, hence the term " induced draught " applied to such fans.

The fans most used are from 22 in. to 38 in. in diameter ; the draught varies from ·04 in. to ·50 in. of water, according to the velocity.[1] The systems most known are those of Blackman, Scott, Davison, Sutcliffe, Sturtevant, and Matthews & Yates.

[1] Much more powerful fans, requiring up to 40 b.h.p. are required for continuous kilns.

The following are the usual sizes :—

Diameter. Inches.	Number of Revolutions.	Volume of Air moved per Minute. Cubic Feet.	Horse-power Required.
14	1200	3,533	$\frac{1}{2}$
22	1000	7,067	$\frac{3}{4}$
27	850	14,134	1
33	750	21,201	$1\frac{1}{2}$
38	700	28,268	2
44	600	35,335	3

The fans are usually driven by ropes or belts from a countershaft, but sometimes it is found advantageous to employ a small electric motor or a separate engine.

Heated and Ventilated Dryers.—Artificial dryers may be divided into three classes :—

(1) Dryers heated but not ventilated.
(2) Dryers with fixed shelves—heated and ventilated.
(3) Dryers with movable platforms—heated and ventilated.

In dryers of the first class waste heat or other means of heating is employed, but there is no proper ventilation, the renewing of the air being accidental (by aeration). The temperature attained is never very high. Dryers of this type are often placed in or near the moulding shed. The ware is usually placed on shelves as in the case of aeration-dryers.

The arrangements adopted vary according to the source of the heat utilized, the process of manufacture, the nature and number of the articles to be dried, and other local circumstances. They can, however, be divided into three groups :—

(*a*) *Dryers placed by the side of or above a kiln and utilizing its waste heat* (Fig. 104) are much used in brickworks, tile factories, drain-pipe factories, etc. The drying is effected economically, but it is often irregular, and is greatly influenced by outside atmospheric conditions.

The kiln is usually placed in the centre of the structure, of which the upper part is occupied by the dryer. Much of the drying is effected by means of ventilation or aeration, air entering and leaving through the windows and the lantern roof. The heat from the kiln is sufficient to raise the temperature inside the structure to ensure natural ventilation and to shelter the ware from frost.

(*b*) *Dryers heated by circulation of hot air, hot water or steam* are frequently used in potteries, porcelain works, etc., where waste heat from the kilns is unsuitable. The articles are generally dried on shelves placed in the making sheds, and the air around them and in the sheds generally is heated by flues near the floor. Ventilation takes place equally by the windows and by special openings. The heating varies according to the outside temperature and the source

of heat. This arrangement enables the makers of the ware to supervise the drying, but it is not economical, and compels the men to remain in a warm, damp atmosphere to the injury of their health. This objection may be avoided, in some works, by taking the goods

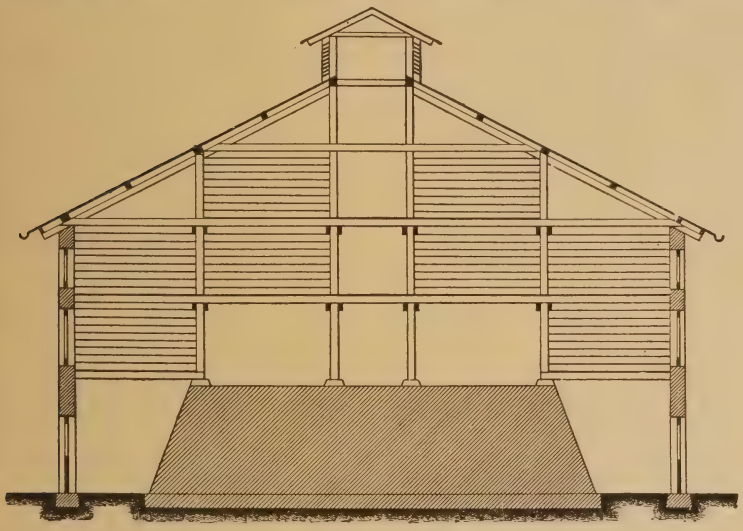


Fig. 104.—Dryer above kiln.

from the workshops into a separate drying-room heated in the manner described.

(*c*) *Dryers heated by flues placed below the floor, in a building* (*a*) *used for making and drying, or* (*b*) *one exclusively reserved for*

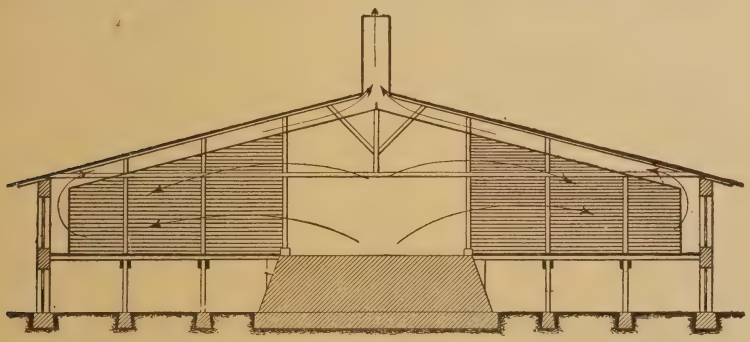


Fig. 105.—Dryer above and around kiln.

drying.—The first of these arrangements is seen chiefly in manufactories of refractory ware where the size of the pieces is too large to allow them to be moved when in a damp condition. The second arrangement is used for drying bricks, tiles, large pieces of pottery,

and many kinds of small ware. In both, the heating is effected by pipes below the ground level connecting the kilns and a chimney; or special fireplaces are employed, the combustion-products circulating in zigzag flues under the floor before reaching the chimney; these flues are covered with plates of sheet-iron or with terra-cotta slabs, the thickness of which diminishes in proportion to their distance from the fireplaces. Instead of hot gases, steam may often be used with advantage, as there is less risk of overheating the dryer. This is usually termed a *hot-floor dryer*.

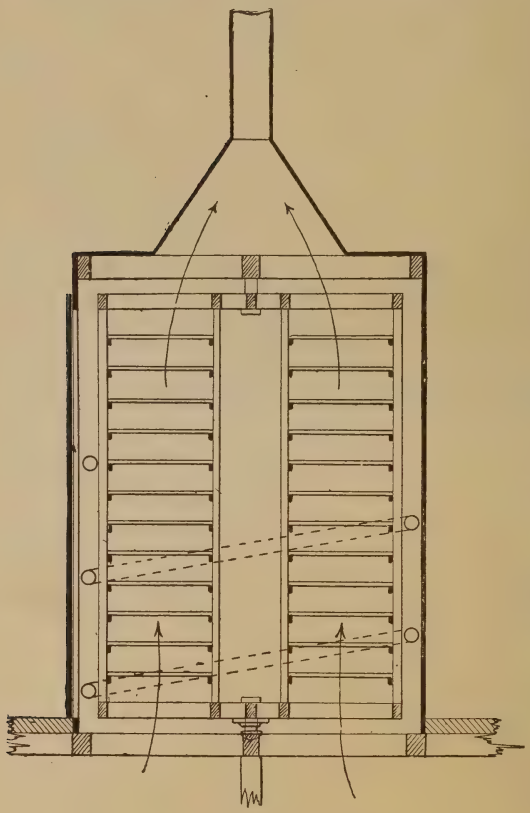


Fig. 106.—Stove dryer.

In heated and ventilated dryers with fixed shelves the air is renewed by means of flues or ventilators, the pieces of ware remaining throughout the drying in isolated chambers. These dryers may be divided into three groups :—

(*a*) *Dryers placed by the side of or above a kiln, in order to use its waste heat.*—They are usually employed in brick or tile works possessing a continuous or Hoffman kiln (see Chapter X). The kiln is covered by a large building shown in transverse section in Fig. 105, divided in its length into six, seven, or eight chambers, from 13 ft. to 20 ft. wide. The air above the kiln is heated by radiation, and traverses these chambers before passing under the roof, and escaping by a central flue. The heat furnished by the kiln is usually insufficient, and this arrangement has little advantage over that shown in Fig. 104.

(*b*) *Dryers formed by chambers entirely isolated and heated by means of a system of pipes in the lower part of the dryer, the ventilation taking place by means of a flue at the top.*—This arrangement is

frequently employed in potteries. The temperature of these chambers can be kept constant, the ware being placed on or removed from the shelves by the workmen who enter the dryer, but as working in hot rooms is very trying, it is preferable to arrange several drying stoves, and to make them work intermittently, stopping the heating when the ware in one stove is dry, and commencing it again when the stove has been emptied and filled afresh. In another form of dryer of this type, the shelves are fixed around a vertical axis and enclosed in a circular casing provided with one or more sliding doors (Fig. 106), to enable the damp pieces of ware to be placed on the shelves and the dry ones removed without entering the dryer.

Fig. 107.—Revolving dryer.

The heating is effected by steam piping arranged spirally, the air entering at the lower end and passing out at the top. The heating is continuous. For larger outputs several of these frames can be grouped together round a central vertical axis (Fig. 107). The rotary movement is only to facilitate the placing of the ware on the shelves, and has no influence on the drying.

In still another modification, termed a *mangle*, the dryer is rectangular in plan and 15 to 20 ft. high ; inside is a series of shelves mounted so as to form a vertical conveyor. The heat is supplied by steam pipes in the base of the dryer, or warm air, heated in an independent heater, is passed through the mangle.

(c) *Dryers in the form of tunnels, the wares being placed on fixed shelves, or mounted on wagons.*—The latter are not moved during the drying, but are only used to reduce the labour of filling and emptying the dryers. The heating is done by currents of hot air circulated by flues or fans. A very simple dryer of this kind is shown in Fig. 108, and consists of two or more parallel tunnels in which are placed temporary shelves. The hot air from a heater enters one end of each tunnel, is distributed through it by a longitudinal sub-floor flue, and passes out charged with moisture at the

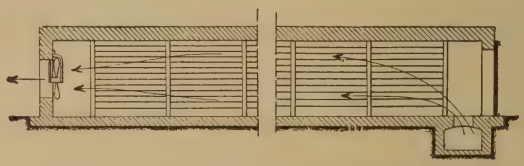


Fig. 108.—Plan of intermittent tunnel dryer.

other end of the dryer, being drawn out by a fan. In this kind of dryer it is easy to evaporate the water from the ware placed at the entry of the tunnel, but as the air passes along towards the other end it cools, causing the moisture to condense on the ware placed there, and tending to soften and distort them.

In the dryer shown in Fig. 109 this drawback is partially avoided. The tunnels are, as in the preceding case, placed side by side, but the hot air enters through the sub-floor flue uniformly throughout the length of the tunnel. Waste heat or steam can be utilized or air heated in special furnaces may be used.

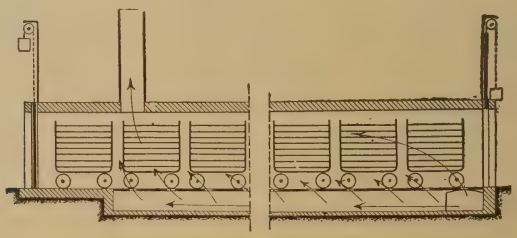


Fig. 109.—Section of tunnel dryer.

The subdivision of the dryers can be pushed still further, as indicated in Fig. 110. In this arrangement, proposed by Hotop, the shelves are fixed in a long gallery. The hot air entering by an upper flue is distributed through the apertures between the ranges of shelves, and passes out through a series of similar openings in the floor communicating with a flue, or *vice versa*.

All these drying tunnels must be carefully regulated to avoid too speedy a drying at the beginning, and a waste of heat at the end by heating the ware already dry.

The chief objection to this class of dryer is its intermittent action, which causes a considerable amount of heat to be lost by cooling and re-heating the dryer. This loss is avoided by working the dryers continuously, as those in the next section.

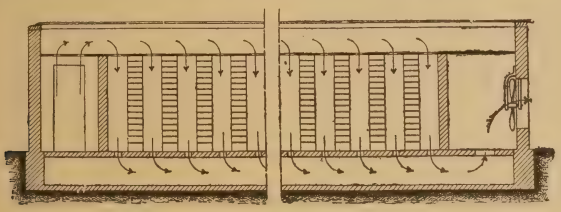


Fig. 110.—Hotop's dryer.

Dryers heated and ventilated, with movable shelves, have a continuous action. The pieces of ware are placed on shelves mounted on wagons, which are methodically pushed through a tunnel, the damp ware being introduced at one end and the dry ware being removed at the other. The arrangements employed for this purpose are of three kinds :—

(*a*) *Drying stoves in which the air moves in a contrary direction to the ware* (Fig. 111), the hot air being introduced at one end of a tunnel and removed at the other by a fan. When the last wagon in the tunnel is dry it is drawn out, and another, laden with damp pieces of ware, is pushed in at the opposite end. The wagons are

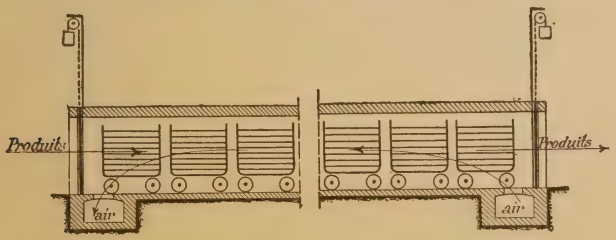


Fig. 111.—Inverse dryer.

moved by winches or cranes, the tunnel floor being slightly inclined so as to facilitate the process.

As stated on page 158, it is desirable to heat the air as much as possible, considering the nature of the goods. If the air enters the dryer at 60° C. and passes out saturated with water vapour at 24° C., there is an expenditure of 1030 calories per kilogramme of water evaporated. When the air enters at 100° C. and passes out at 31° C., the expenditure is 930 calories. It is necessary to add to these figures the heat removed by the ware and wagons, say 60 calories in the first case and 100 in the second, the exterior temperature being supposed equal to 0° C. Finally, it is desirable to increase the expenditure by 25 per cent in order to take into account the various losses of heat, so that in the most favourable case the heat necessary

to evaporate 1 kilogramme of water will be (930 + 100) × 1·25, or about 1300 calories.

(*b*) *Drying stoves in which the air travels in the same direction as the ware, which it heats progressively* (Fig. 112).—In such a dryer the air enters at one end of the tunnel, is heated by steam piping and by some other form of heater, so that its temperature increases as it advances in the tunnel. As the air advances, it becomes charged with water vapour, passing out at the other end with the maximum of heat. The wagons are moved as in the preceding dryer. The formulæ given on page 158 do not apply in this case.

The heat expended will be :—

For the steam	606·5 − 0·695 = 605·80
For the air . . .	1·3 × 0·237 × 60 × 7·35 = 135·72
For the body	5 × 0·2 × 60 = 60
	801·52

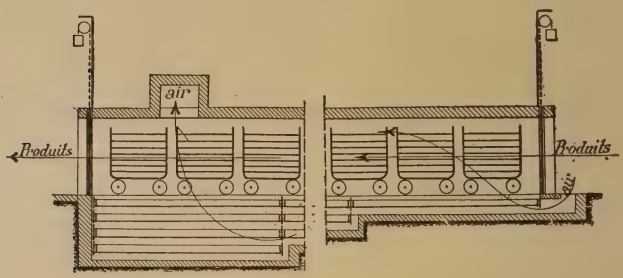
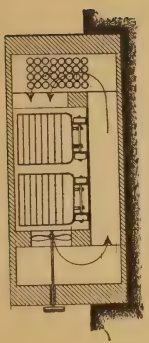


Fig. 112.—Direct dryer.

a total which, increased as previously by 25 per cent, gives an expenditure of about 1000 calories. In some cases, it can be reduced by employing the departing air to heat that which has just entered. Thus, if the air instead of going out at 60° C. has its temperature reduced to 30° C. by means of calorifiers, the heat which can thus be recuperated is 477·01 calories, and recuperation would then reduce the amount of heat required to 823 calories per kilogramme of water evaporated.

On comparing the direct and inverse tunnel dryers just described, the latter are of a lower thermic capability, and should be used only for utilizing waste heat. The former are of much greater use, but do not lend themselves well to the utilization of waste heat, yet are preferable when heat must be specially provided. In direct dryers (Fig. 112) the chief difficulty consists in obtaining a uniform atmosphere throughout the section. If mechanical means are not employed to effect the circulation of the air, the upper part of the dryer is filled with a warm, damp atmosphere which has little drying power. The system proposed by Moeller & Pfeiffer (Fig. 113) completely obviates this difficulty. In a tunnel, A, several ranges



Section on *m*—*n*.

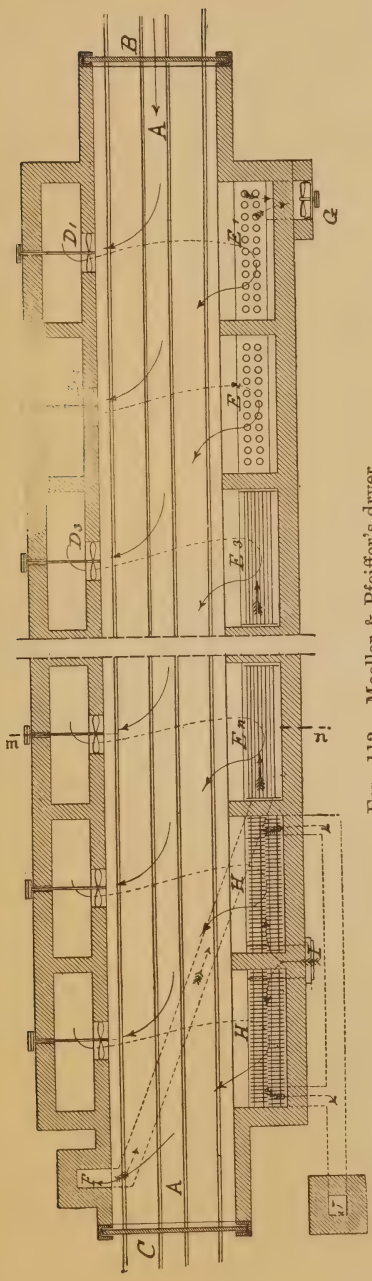


FIG. 113.—Moeller & Pfeiffer's dryer.

of wagons laden with ware to be dried enter through the door B, and pass out through C. The outside air enters through the door B, which is partially opened, being drawn in by a first fan, D_1, which forces it through an underground flue to the other side of the tunnel, where it meets the pipes of the heater, E_1, E_2; after being heated in contact with them it re-enters the tunnel, travelling obliquely, being drawn in by a second fan, D_2, which likewise forces it to pass on to a second calorifier, E_2, and so on. The air thus follows a spiral path, becoming more and more heated as it advances, before going out through a side flue, F. From F it is drawn through the heaters, E_n, E_3, E_2, E_1, where it gradually loses its heat by transmitting it to the air circulating in the tunnel, until it reaches the fan, G, which discharges into the atmosphere. The water vapour which it contains is condensed while restoring the latent heat of evaporization, and passes out of the dryer in the liquid state at a slightly raised temperature. The last two or three heaters, H, are heated by a special stove, I, the gas of which escapes by a chimney, J.

Tunnel dryers are chiefly used in brick and tile works (see Chapter X).

By regulating the proportion of moisture in the air as well as the temperature, even the most delicate ware can be dried rapidly, as in the Proctor and Carrier dryers.

Drying by absorption in plaster moulds is much used in making pottery ware, and in the drying of small quantities of special bodies. The absorbing properties of the plaster act exactly in the same way as evaporation in a dry atmosphere. The body gives off by a capillarity a part of its moisture to the plaster, and this action is the more powerful the drier and thicker the plaster. The only difference between drying by evaporation and by absorption consists in the impossibility of complete drying by the latter. It necessarily stops at the moment when the moisture in the plaster is equal to that in the body, so that if complete drying is required absorption must always be followed by drying by evaporation. Two processes are employed for this purpose, according to the size of the ware, the nature of the body and the arrangement of the works. In the first—which is especially applicable to large plastic articles and for small outputs—the article is left to dry for some time in the mould in the workshop where it is made, and when it has obtained sufficient consistency to enable it to be taken from the mould it is placed on a shelf and dried by evaporation by one of the methods previously indicated. In the second process—which is employed chiefly for the manufacture of a large number of small pieces—the mould containing the article is at once placed in a heated dryer, where the drying takes place simultaneously by absorption and by evaporation ; later, the article is taken out of the mould and the drying continued until the ware loses its last traces of moisture.

CHAPTER VII.

GLAZES.

(1) Composition and Properties.

Glazes are vitreous coatings used to cover bodies, either to decorate them or to make them impermeable to water. They should partly combine with the body itself, in order that the two may adhere closely. Their chemical composition is nearly as variable as that of the bodies, but they may be considered as " glass " in the widest meaning of that word. Glazes differ from glass in not being solely composed of silicates ; they sometimes contain quite as much borate or phosphate, and among the bases may be tin oxide, while sometimes the alkalies are quite absent. Most glazes also differ from glass in the proportion of alumina they contain ; this is an important constituent, as it increases the adhesion of the glaze to the body. The fusibility of glazes is much more variable than that of true glass ; sometimes they vitrify at a temperature lower than that for fusing borax ; at other times, however, they need a temperature high enough for burning porcelain. As in the case of glass, the molecular constitution of glazes is not certainly known.

Glazes, like glasses, are amorphous bodies, that is to say, their molecules have not taken a certain grouping together, as is the case in crystallized bodies. It is only exceptionally that the phenomenon of crystallization occurs in glazes and the presence of " wollastonite " (a silicate of soda and lime) or of " oligoclase " (a silicate of soda, alumina, and lime) can then usually be detected. By increasing the proportion of the alkalies, or by introducing several bases into the glaze and by not giving this latter a definite atomic composition, a regular grouping of the molecules is made more difficult and crystallization is prevented. This shows the importance of the alkaline silicates, and the mistake into which those potters have fallen who have wished to give glazes a definite chemical formula.

Some substances, when introduced into glazes, do not combine, but remain suspended and thus render the mass opaque ; for this reason they are used to destroy transparency. The oxides of tin, zinc and alumina, and phosphate of lime are of this kind. If the temperature of the kiln is increased, these bodies tend to combine, at least partially, and to be dissolved in the amorphous glaze.

Quartz acts differently ; if some of it is added to a silicious glaze, i.e. one in which all the bases are saturated with silica, it dissolves

in the glaze without altering the transparency. But, under certain circumstances, it may separate afresh by crystallizing in the form of cristobalite or tridymite. This change in its constitution, which is characterized by the alteration of its density from 2·6 or 2·7 to 2·2 or 2·3, shows that it has not been simply dissolved, but that it has undergone inversion into one of the other forms of silica.

From the foregoing it may be concluded that glazes are amorphous substances, formed of alkaline, earthy, or metallic silicates and borates, but their molecules are not in regular groupings. They are liable to dissolve certain substances, notably quartz, and to keep others suspended. Their molecules also tend, under certain circumstances, to group themselves together so as to form definite compounds which crystallize in the mass, and may form a decoration on the ware.

Chemical Composition.—*Silica* is the preponderating oxide in glazes ; it may be found either combined with the bases or in solution, but it always has a density of 2·2 or 2·3. Its amount may vary from 25 to 75 per cent ; the greater it is the higher will be the temperature required for fusing the glaze.

Boric or *boracic acid* plays the same part as silica, but the borates are much more fusible than the corresponding silicates. It makes the glaze harder and more brilliant, and acts upon the colour of certain metallic oxides, as may be seen in the chapter relating to Decoration. On account of its high price, it is only used for fine glazes, the proportion used in a glaze scarcely ever exceeding 10 per cent.

Phosphoric acid is less used, and then chiefly in glazes in the form of calcium phosphate, suspended in the mass to make it opaque.

Alkalies.—Soda and potash with silica and boracic acid form very fusible compounds, but as they are soluble in water they cannot be used alone, and other bases must be added to form insoluble compounds. They make the glazes more clear and transparent, and give special colours to metallic oxides. Their proportion may be as high as 25 per cent. Potash makes more fusible compounds than does soda.

Lime is often used to make double silicates and borates of alkalies and lime. It has, however, a tendency to cause the formation of crystals. With boracic acid it makes a fusible glass ; but with silica at a high temperature it only forms a whitish mass, which is more or less translucent. Its proportion may be as high as 30 per cent. Lime is seldom used as such in glazes, it being usually added in the form of whiting—a calcium carbonate.

The other alkaline earthy bases possess the same properties as lime with different degrees of fusibility. *Magnesia* is more refractory, *strontia* more fusible, and *baryta* more so than strontia ; the equivalents of these bases vary in the same order as their fusibility, being as follows :—

	Mol. Equiv.
Baryta	153
Strontia	103
Lime	56
Magnesia	40

Alumina is found in glazes, principally in the form of silicate of alumina (calcined clay). In a small proportion, with alkaline silicates, it forms glasses which are transparent, hard, and very slightly inclined to crystallize. In larger proportions it remains in suspension, making the glazes partially opaque or translucent. It does not combine well with alkaline borates or silicate of lead. In every case its introduction into a glaze has the effect of noticeably diminishing its fusibility.

Lead oxide (usually in the form of white lead, litharge, or red lead, and less satisfactorily as litharge (lead sulphide)) is much used to increase fusibility. It forms, with silica and boracic acid, glasses which are insoluble in water and are attacked by acids, provided they contain at least one equivalent of boracic acid or silica to one equivalent of lead oxide. It has a slight tendency to cause crystallization, and acts on the colouring of certain metallic oxides.

Bismuth oxide acts in the same way as lead oxide, making still more fusible compounds.

Tin oxide does not form transparent glazes, but remains suspended in them, making them opaque. This opacity diminishes with an increase in temperature. It is this property which causes it to be very often used in the manufacture of opaque glazes.

Antimony oxide fulfils the same part as tin oxide, but it is more fusible ; although colourless in itself, it can impart a yellow colour to glazes.

Zinc oxide also remains in suspension in silicious glazes, but it dissolves in boracic acid. In spite of its whiteness, it often modifies the colours of other metallic oxides. It is very slightly fusible.

The *colouring oxides* introduced into glazes to give them decorative properties will be studied in Chapter IX.

Action of the Glaze on the Body.—As glazes can dissolve quartz and keep other substances suspended in their mass, it is natural that, under certain circumstances, they should act as flux or solvent on the body at the moment of their fusion. But in order that this action may take place, it is necessary for the temperature of the fusion to be kept up for a sufficiently long time. Under these conditions and when the glaze is sufficiently basic, especially if the proportion of the alkalies in it is raised, it can dissolve a certain proportion of free silica. It can also combine with the iron oxide which certain bodies contain, and by spreading into the mass may cause yellowish spots. When this action of the glaze on the body takes place, it causes a modification of the chemical composition of the glaze, which thus becomes more silicious. The importance of this must not be exaggerated, as it is by some potters, so as to assume the definite formula which they give to glazes corresponds

with their true composition. On the other hand, it would be equally erroneous to neglect the use of formulæ when studying the agreement which ought to be found between the respective expansions of the body and the glaze. There is, or at least there ought always to be, between the body and glaze an intermediate zone in which they are mixed up, and which serves as a transition point.

Classification and Terminology.—Glazes differ from one another chiefly in their chemical composition, which affords the means of deciding their most important physical properties, e.g. hardness, transparency, solubility, etc. A satisfactory classification of glazes is based on the composition which, whilst taking no account of unimportant substances present only in very small proportions, characterizes them by two, three or, very seldom, four principal bodies :—

(i) *Plumbiferous* glazes with a large proportion of lead.

(ii) *Alkaline* glazes with a large proportion of soda or potash, or alternatively of lime or magnesia, though the two latter are alkaline earths.

(iii) *Boracic* glazes with a large proportion of boric oxide.

(iv) *Silicious* glazes with a high proportion of silica.

The various groups overlap considerably, yet they serve to classify glazes in a manner which is convenient for many purposes. Some ceramists have classified glazes according to the relative proportions of the acids and bases which they contain, into acid, neutral, or alkaline glazes ; this distinction—which does not take into account the different properties of the two acids and of the various bases—rests only on theoretical grounds which are still in dispute, and it has not been generally accepted.

Whatever method of classification is used, it is convenient to retain also the following terms, which have been sanctioned by long use :—

Soft glazes (Fr. *vernis*) are transparent glazes fusible at a low temperature ; they are generally highly plumbiferous, and are used to cover certain earthenware (faience) with a thin glossy coating.

Enamel (Fr. *email*) is a term applied to several kinds of glaze, the chief being :—

(i) Soft glazes applied to ware which has been previously covered with glaze of greater refractoriness, as the soft glazes (usually coloured) which are used in the over-glaze decoration of porcelain and in the repairing of defective earthenware and porcelain.

(ii) Opaque glazes, *e.g.* the stanniferous enamels containing tin oxide as an opacifier. There is a tendency among potters to regard majolica ware—a coloured body covered with an opaque glaze—as "enamelled," and similar ware with a transparent glaze as "glazed."

(iii) Glazes which are applied to metallic surfaces, as *enamelled iron*, *enamelled silver*, etc.

(iv) Soft glazes generally, though so loose a use of the term is in many ways unsatisfactory.

Hard glazes (Fr. *couvertes*) are transparent glazes which require to be fired at temperatures above 1200° C. When cold, they produce a hard, glassy coating, usually of moderate thickness, and they usually contain alumina and a calcareous base, with little or no lead. They are used to cover vitreous pottery (stoneware, porcelain), sanitary ware made of a fireclay body, and some kinds of faience made of a fine body.

The terms *soft glaze*, *enamel*, and *hard glaze* do not have a rigid significance, and ought really to be considered as synonyms of the word glaze; it is wise to accompany them with the name of the principal substances which enter into the composition—thus, a *boracic alkaline glaze*, an *alkaline plumbiferous enamel*, a *calcareous hard glaze*, etc.

(2) Raw Materials.

Silica and Silicates.—Silica is usually introduced into glazes in the form of quartzose sand or flint which have been finely ground, sifted, and washed. A very small proportion of alkalies may have a serious effect on glazes if they are present in more than negligible proportions. It is often advantageous to calcine the quartz or flint before grinding it, so as to prevent it from expanding when in use (see Chapter III).

Among the silicates, the *felspars* are those most used in the manufacture of glazes. These are alkali alumino-silicates, usually containing a small proportion of lime, iron oxide, and magnesia (p. 41); only the purer sorts—particularly those free from oxide of iron—should be used.

Among the felspathic rocks the ones most used in glazes are *pegmatite* from St. Yrieix and *Cornish-stone* from Cornwall; they should be finely powdered before being mixed with the other ingredients of the glaze.

In some glazes, *kaolin* (*china clay*), *plastic clay*, *grog* or *calcined clay* are used. These materials, which have been already described, lessen the fusibility and usually impart an opacity or translucency to the glaze.

Glasses, such as are generally made in glass works, are sometimes used for common glazes. They are more easily worked than felspars, and introduce alkalies without the necessity of fritting, but are liable to cause crazing (possibly because they are deficient in alumina). Another serious defect is that their compositions vary, so that an analysis of each batch is necessary to obtain exact mixtures. The following are the usual limits to the variations in the composition of commercial glasses :—

	Window Glass.	White Bottle Glass.	Crystal Glass.
Silica . . .	73 to 69	72 to 57	51 to 61
Alumina . . .	0·8 „ 0·7	2 „ 5	0 „ 2
Lime . . .	11 „ 13	8 „ 31	0 „ 4
Alkalies . . .	12 „ 16	5 „ 17	6 „ 14
Oxide of lead . .	—	—	28 „ 40

Boracic Acid and Borax.—Boracic or boric acid crystals contain a large proportion of water and correspond to the formula B_2O_3, $3H_2O$, and contain 56 per cent of boracic acid and 44 per cent of water. They easily melt in the water of crystallization; but must be heated more strongly to make them anhydrous. *Refined boracic acid* is sold in fine white flakes containing 96 to 97 per cent of boracic acid. In *Tuscany boracic acid* the crystals are larger, yellowish, and only contain from 85 to 90 per cent of the pure acid; the impurities consist of ammonium sulphate, hydrated silica, organic matter, and traces of lime.

Boracic acid is often adulterated and should be tested by dissolving it in boiling water, filtering, and weighing the insoluble residue. Boracic acid is also used in the form of white *borax*, hydrated borate of soda—represented by the formula Na_2O, $2B_2O_3$, $10H_2O$. When exposed to the air, the glassy crystals of borax become cloudy and whitened on account of the evaporation of a part of the water of crystallization. When borax is gently heated, this water completely evaporates and the anhydrous borax forms a white powder; at a higher temperature it melts and, on cooling, becomes a vitreous or glassy mass. Borax occurs in the form of impure sodium and calcium borate in the north of Chili and in California. The crude salt is dissolved in water, a solution of sodium carbonate is then added to precipitate the lime, which is removed by filtration. The solution is either heated artificially or is exposed to the air in large open pans and commercial refined borax is obtained by several successive crystallizations. The product so obtained is almost pure, and contains 37 to 38 per cent of boracic acid and 16 to 17 per cent of soda, the remainder being water.

The crude material sold as *natural borax*, *tincal*, and *American borax*, which usually contain a large proportion of impurities and their composition is very variable, are sometimes used in glazes, but are unsatisfactory; it does not pay to purify them on a small scale, so that the much purer *refined borax* should be used. Although borax purchased from a reliable firm is usually satisfactory, it is wise to test it by dissolving a definite weight of borax in water, colouring the solution with blue litmus, adding " normal " sulphuric acid from a burette, and noting the number of cubic centimetres required to change the colour of the solution to a distinct red. By repeating this test with an equal weight of pure borax, the relation

of the two numbers of cubic centimetres of acid used shows the proportion of pure borax in the sample tested.

Alkaline Salts.—The chief alkaline salts used in the ceramic industries are the various forms of *soda* (sodium carbonate), *potash* (potassium carbonate), *sodium chloride*, *sodium sulphate*, *potassium nitrate*, with which potash alum may conveniently be included, though it is not usually regarded as an alkaline salt.

Soda—a term which, strictly, is applied only to *sodium oxide* (Na_2O), but is also commonly applied to sodium carbonate, or *carbonate of soda* (Na_2O, CO_2); the latter contains 58·5 per cent of soda and 41·5 per cent of carbon dioxide. Commercial carbonate of soda, which usually contains only 57·5 to 58·0 per cent of soda, is sufficiently pure to be used in most glazes; it must be stored in tightly closed vessels in a dry place, as it is hygroscopic. Care must be taken not to confuse it with *washing soda*, which is sold in the form of large crystals of the formula Na_2O, CO_2, $10H_2O$, containing only 21·7 per cent of soda, 15·4 per cent of carbon dioxide, and 62·9 per cent of water. Crude carbonate of soda made from ashes must be avoided, as the impurities in it cause unpleasant irregularities in the glazes.

Potash—a term which, strictly, is applied to *potassium oxide* (K_2O), but is also commonly applied to potassium carbonate or *carbonate of potash* (K_2O, CO_2); the latter contains, when pure, 68 per cent of potash and 32 per cent of carbon dioxide, but it is wise to test it. It is very hygroscopic, and ought always to be dried before being used. That made from the ashes of vine is usually very impure, but refined potash is quite satisfactory for glazes.

The quantity of soda or potash in the respective carbonates may be tested [1] by following the method already described for borax. A suitable weight of the salt is dissolved in water, the solution is coloured with litmus, and "normal" sulphuric acid is added to it from a burette until the liquid just becomes red in colour. If the "normal" acid contains, for example, 49 grammes of sulphuric acid per litre, and if n is the number of cubic centimetres added to a sample of soda, the amount of sodium carbonate in the weight of sample tested will be $n \times 1{\cdot}0816$. If m is the number of cubic centimetres of "normal" sulphuric acid added to a sample of potash, the amount of potassium carbonate in the weight of sample used will be $m \times 1{\cdot}4081$.

Sodium chloride or sea salt (NaCl) is sometimes used in glazes, but its most frequent use is for glazing stoneware by volatilization (see *Salt-glazing*).

Sulphate of soda (Na_2O, SO_3, $10H_2O$), or *Glauber salt*, is not much used in pottery except in some cheap frits, and even then it is better to use carbonate of soda, which is far less likely to cause trouble.

[1] If the samples tested contains a mixture of carbonate of soda and potash, this method is not applicable.

If sulphate of soda is used, it should be calcined so as to eliminate its water of crystallization.

Nitre, saltpetre, or *nitrate of potash* (K_2O, N_2O_5) was formerly the chief means of introducing potash into a glaze, but its chief use nowadays is to free glazes from any organic matter which may be present, and to increase the potash-content of some others to an extent which is impracticable with felspar. Nitre is sold commercially in the form of small crystals, which are usually sufficiently pure.

Potash alum (Al_2O_3, $3SO_3$, K_2O, SO_3, $24H_2O$) is sometimes used to introduce potash and alumina simultaneously into glazes. It is sold in two forms—(i) crystals containing a large proportion of water of crystallization ; and (ii) as " burnt alum," which is prepared by calcining the crystals. It often contains iron oxide, but may be purified by successive crystallizations. When pure, it contains about $10\frac{3}{4}$ per cent of alumina and 10 per cent of potash.

All the alkaline salts mentioned in this section are soluble in water, so that, before they can be used in glazes, they must be converted into insoluble substances by *fritting* (p. 179).

Alkaline Earths.—A term which may briefly be described as including the compounds of calcium, magnesium barium, and strontium. The ones which are the most important in the production of glazes are :—

Lime (calcium oxide, CaO), which is seldom used as such in glazes on account of its solubility in water, but is chiefly introduced into glazes in the form of the carbonate and the sulphate.

Carbonate of lime (CaO, CO_2), chiefly in the form of *whiting, marble, Paris white*,[1] or *Spanish white*, all of which have the same composition and are commercially pure calcium carbonate. These substances form the best means of introducing lime into a glaze ; they are all excellent fluxes. On heating to about 800° C., all these forms of calcium carbonate decompose slowly, yielding 56 per cent of their weight of lime.

Sulphate of lime or *gypsum* is sold in the form of crystals, hydrated sulphate of lime (CaO, SO_3, $2H_2O$), which contains, in a pure state, 31·86 per cent of lime and 46·51 per cent of sulphuric acid ; the latter is only given off at a high temperature.

Plaster of Paris is prepared by heating gypsum until only one-quarter of its water of hydration remains and grinding the product to a fine powder. It must not be confused with *builder's plaster*, which is lime, or a crude mixture of lime and calcium carbonate. The chief objection to plaster of Paris in glass is the evolution of sulphuric oxide at high temperatures.

Magnesia may be added to glazes in the form of (i) dolomite (a mixture of the carbonates of lime and magnesia) ; (ii) talc (a hydrated silicate of magnesia) ; (iii) magnesite (magnesium carbonate) ; or (iv) magnesia.

[1] Not to be confused with *Plaster of Paris*, which is a sulphate.

Baryta is used in the form of barium sulphate, barytes, or heavy spar (BaO, SO_3), containing, when in a pure state, 65 to 66 per cent of barium oxide. The native carbonate (witherite) is also used, but the artificially precipitated carbonate is superior, being both purer and in a finer powder.

Strontia is seldom employed in glazes.

Oxides and Salts of Lead are used, in the form of litharge, red lead, white lead, and galena.

Litharge or *massicot* (PbO)—lead monoxide—is sold in the form of brilliant lamellar crystals, or of reddish-yellow powder. It may also be obtained by heating metallic lead in air. The best litharge contains only traces of iron and copper; some samples are very impure. Litharge ought to dissolve entirely in dilute nitric acid. If there is any residue it is usually antimonic acid, sulphate of barium, or even ochre, sand, or powdered terra-cotta—all of which are used as adulterants.

Red lead (Pb^3O^4 or $2PbO, PbO^2$) is obtained by heating massicot to about 300° C. It is a beautiful red powder, which darkens when heated and is changed to lead monoxide with the liberation of oxygen, 100 parts by weight of pure red lead yielding 97·37 parts of the monoxide. Red lead always contains a noticeable proportion of massicot, even when it has been heated several times. Thus, red lead fired once contains 50 per cent of it, and that called "eight fires," which has been heated eight times, still contains 25 per cent.

When heated with dilute nitric acid, red lead ought not to produce any effervescence nor to leave any insoluble residue.

Lead carbonate (PbO, CO_2) contains, when pure, 83·52 per cent of lead monoxide, which is formed when the carbonate is calcined. The simple carbonate is seldom used in glazes, as white lead is more bulky, and is usually more pure.

White lead—a basic carbonate of lead, $2(PbO, CO_2), PbO, H_2O$—should be dried before mixing with other glazed materials. It decomposes on heating, carbonic acid being given off and lead monoxide remains.

White lead was, at one time, much adulterated with sulphate of lead, sulphate of baryta, plaster, or chalk.

Lead ore or *galena* (PbS) is a grey mineral with a metallic lustre. Chemically, it is a sulphide of lead, containing, when pure, 13·39 per cent of sulphur and 86·61 per cent of lead. It is seldom pure, and is almost always mixed with gangue (vein-stone). Its variable composition, as well as the inconvenience which may result from the liberation of sulphurous fumes in the kiln, limit the use of galena to common ware, for which it has the further advantage of being exempt from many of the legal restrictions attending the use of other lead compounds.

Oxide of Tin and Tin Ash.—The *oxide of tin* used in pottery is the dioxide (SnO_2), or stannic acid, which is sold in the form of a white powder and often in a hydrated form (SnO_2, H_2O). The latter decomposes at a red heat, giving a slightly yellowish powder

—anhydrous tin oxide. It may be prepared by adding nitric acid to the metal tin ; the white powder thus obtained is washed and ground in water ; but it is better to buy it. In trade, a distinction is made between oxide of tin manufactured in acid, as described, and that obtained by the oxidation in the air with the action of the heat on the metallic tin.

Oxide of tin is also used in the form of *tin ash*—a stannate of lead containing 15 to 50 per cent of tin and 85 to 50 per cent of lead. It is usually manufactured in the pottery, the two metals being mixed together in the proper proportions, and heated in a shallow, open vessel over a furnace. The metals melt and gradually become covered with a layer of yellowish-white powder, which is the tin ash ; the mass is stirred continuously, and the powder removed from time to time with an iron scraper. For very large outputs a reverberatory furnace or frit kiln should be used. The tin-ash powder is afterwards washed to separate any metallic particles that may be left unattacked ; it is then dried and ground.

Various Materials.—Amongst other materials used in glazes may be mentioned :—

Fluorspar, or *fluorite* ($CaFl_2$), which is a fluoride of calcium, and *cryolite* ($3NaFl$, $AlFl_3$), or double fluoride of soda and alumina ; both are used as fluxes. They decompose at a red heat ; the bases —lime, soda, and alumina—in them mix with the other elements of the glaze, and the fluorine combines with the silica to form silicon fluoride, which volatilizes if the temperature is sufficiently high. If such is not the case, or if the glaze is not sufficiently silicious, the fluoride remains separate and may form saline deposits, which spoil the surface of the glaze. Fluorspar is very little used in pottery. Cryolite is more widely used.

Oxide of zinc (ZnO) is used to make silicious glazes opaque, and also as a flux ; it is about the same fusibility as magnesia, and is prepared by oxidizing metallic zinc. It is sold in the form of a white powder, which is made yellow by calcining, but regains its previous colour on cooling. The best quality is usually sufficiently pure for use in glazes, but some commercial zinc oxide is quite unsuitable.

(3) Manufacture and Application.

The Preparation of the Glazes—in its most complex form—includes the following operations : (1) Preparation of the raw materials ; (2) mixing ; (3) fritting or vitrification ; (4) mixing and grinding in water.

The raw materials ought to be in the form of very fine powders, as pure as possible, and of a composition that does not change on exposure, thus allowing of an exact mixture. As most of the materials are not naturally in this state, they must be ground to the requisite fineness ; alternatively, they may be purchased, ready for mixing, from dealers in potter's materials.

Grinding is done by the different methods shown (Chapter IV) when speaking of the preparation of the body, but it is very important to avoid mixing particles of iron and iron oxide with glazes, and it is, consequently, wise only to use pulverizing machines, the metallic parts of which do not come in contact with the material to be ground. Vertical or horizontal stones (Fig. 11), block-mills (Fig. 35), and ball mills (Fig. 9) lined with stoneware, or porcelain, and with balls of the same material or of flint are all suitable. The grinding may be either dry or in water ; sometimes the materials is passed through a series of mills in succession, this being cheaper—with sufficiently large quantities—than completing the grinding in one mill.

The harder materials, as quartz, flint, feldspar, and cryolite, must be ground with water in order to get them sufficiently fine. Dry grinding must be carried on with precautions to avoid the production of dust, which is very injurious to the health of the workman. Tight cases around the apparatus and suitable systems of ventilation are indispensable ; it is not sufficient to wear masks.

Mixing may be done by weight or by measure ; it is necessary to do this more exactly than with bodies, and care must be taken to take into account the water and volatile substances—carbonic acid, sulphur, sulphuric acid—which the raw materials may contain, and especially the variable amount of moisture and of water of crystallization which may be present. Prior to weighing or measuring them, the materials should be dried and kept in closed places, sheltered from damp.

Fritting and Vitrification.—When the materials have to be ground in water, as is most usual, those which are soluble, such as alkaline salts, boracic acid, and borax, must first be made insoluble. To do this, they are fritted with silica, lime, lead oxide, etc., according to the composition of the glaze, the proportions of base and acid being such as to produce an insoluble compound which is as fusible as possible, so as to reduce the expense of fritting. At the same time, it is wise to avoid having materials of very different densities, which, after having been mixed with water, would be deposited unequally and would destroy the homogeneity of the glaze. This applies especially to materials containing lead or baryta, which are much denser than the others. This defect can be remedied by combining them with other lighter substances, such as silica, etc.

When a material is to be introduced into the composition of a glaze in a very small proportion, making it very difficult to mix uniformly with the others, it should be added prior to fritting.

Fritting consists in uniting materials under the influence of heat, by melting them so as to form a glass. For small quantities this is done in fireclay crucibles heated in special furnaces. When a sufficient heat has been attained, the contents are poured into water to shatter the vitreous mass, and to make it more easy to grind ; the crucible is then refilled. Such crucibles should not contain more than 22 lb. of materials if they are to be easily handled.

They only bear a small number of heatings, and the furnace should be arranged so as to enable any glaze which may run out, in the event of the crucible breaking, to be recovered. When larger crucibles are used, the molten mass is taken out by means of iron ladles or rods, or the crucibles can be pierced at the bottom with a hole through which the molten mass runs, and is caught in a vessel of water.

For very large quantities, reverberatory furnaces are used (Fig. 114). The materials to be fritted are brought on to the hearth, which is horizontal. As fast as they melt they run on to an inclined plane to collect at the lower part of the hearth, from which they can be run off through an opening at the side which, while working, is closed by a plug of fireclay, carefully sealed. A metal or earthenware spout leads the frit into a vessel full of water, in which the frit is collected. The working of the furnace is continuous, the

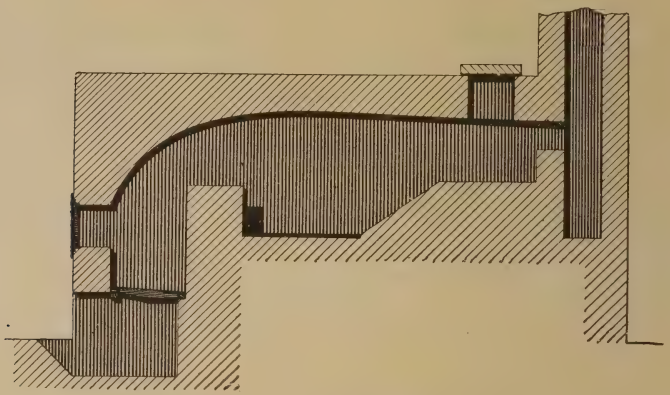


Fig. 114.—Section of frit-kiln.

materials being charged and run off at intervals, without stopping the working. The heat is supplied by a fire at one end, while a chimney at the other creates the necessary draught. The furnace should be at the desired temperature before introducing the mixture, and the latter should be frequently stirred with a wooden pole to make it homogeneous before it is run off.

In some potteries the fritting is carried out in saggers, which are placed in the oven along with others used for burning the ware, and are taken out when emptying the oven. To prevent the frit from sticking to the bottom of the saggers it is necessary to cover the latter with flint, which adheres strongly to the frit, so that this method must be regarded simply as a makeshift and not as a regular method of manufacturing frits.

In order to carry out the fritting effectively it is essential for the raw materials to be well mixed, but it is not necessary to powder them very finely. The alkaline salts, boracic acid and borax, may

be in rather large pieces, and silica and feldspar should be in the form of coarse powder.

The heating ought to be uniform, and it is especially essential in lead glazes that the atmosphere of the furnace be never reducing or smoky, or the lead oxide will be reduced to metallic lead. The heating should be continued until the mass is completely molten and as clear as possible, but it must not be unduly prolonged or loss of alkali will result.

The crucibles and the hearth of the furnace should be made of aluminous fireclay, and should not contain obvious grains of free silica, which might be attacked by the frit and so spoil it.

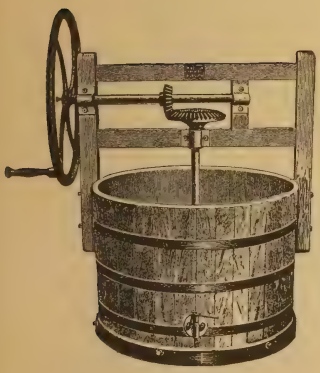


Fig. 115.—Glaze-grinding tub.

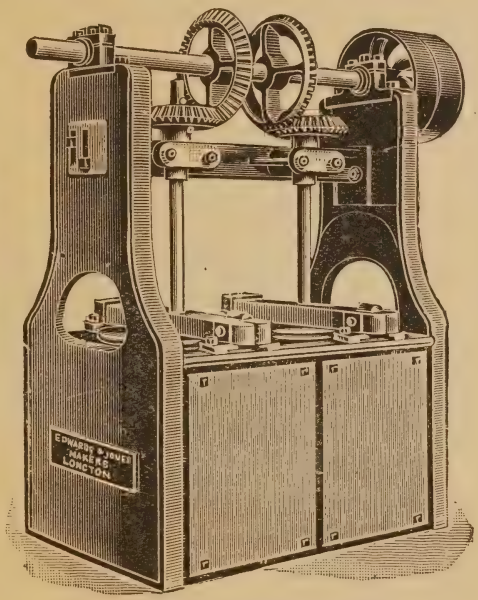


Fig. 116.—Glaze-grinding machine.

Mixing and Grinding with Water.—Some glazes may be made by mixing the dry powdered materials, but this is unusual, and it is preferable to mix the materials by grinding them in water, as this makes the mixture very homogeneous. A blunger (Fig. 19) ought only to be used when the glaze is bought ready for use.

The grinding of glazes in water is usually done between horizontal grindstones, the lower one being fixed, and the upper having a rotary motion. The latter generally has two holes, through which the glaze enters between the stones. A stop-cock, placed on the lower surface of the grindstone, allows the ground glaze to run out. According to the importance of the ware, the mill may be driven by hand or by steam power (Figs. 115 and 116). The diameter of the vat is 14 to 16 in. for the hand machine, and 28 to 40 in. for

those driven by steam power. Block mills (Fig. 35) may be used, but ball mills (p. 69) or Alsing cylinders are now preferred. Those used for grinding glazes can work charges of 20 to 300 lb. for an expenditure of one-eighth to ten horse-power (Fig. 117). The smaller models may be worked by power or by hand. The interior lining of the cylinder is of porcelain or stoneware, and the balls are usually flint pebbles. When the grinding is completed, the solid cover is replaced by a grating, which allows the glaze to run out, but retains the pebbles.

If clay enters into the composition of a glaze, it ought to be added to the ground mixture in the form of a liquid or paste towards the end of the operation, because, if added earlier, it would hinder the grinding of the harder materials.

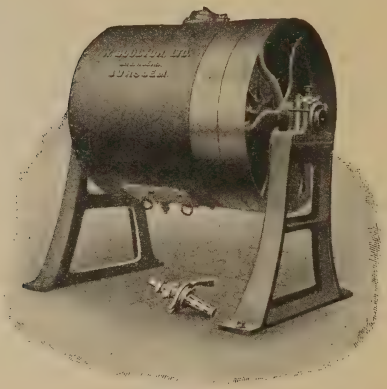


Fig. 117.—Glaze-grinding machine.

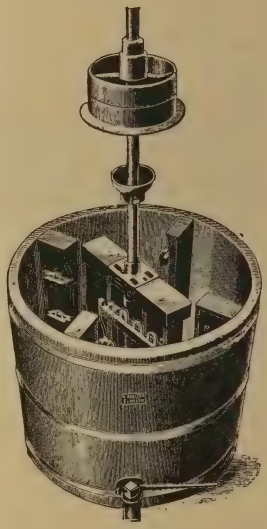


Fig. 118A.—Electro-magnetic glaze-purifier.

The glaze, when ground, is generally sifted to keep out the coarser grains or lumps. The sieves may be of 80-, 100-, or 200-mesh, according to the fineness of the glaze ; it is undesirable to grind the glaze materials excessively fine, however, as this causes them, when fired, to " run together," forming small balls or pellets of glaze, and leaving parts of the ware unglazed.

When the sieves are fine, the glaze must be very fluid to pass through them, and as it is then too " thin " to be applied to the ware, it is best to let the glaze settle until it is of a suitable consistency.

The glaze-slip should always be freed from particles of iron by passing it through a trough or vat (Figs. 118A, 118B) containing electro-magnets, some being fixed whilst others are movable, so as to

act as agitators. When a vat is used, the treated glaze is emptied through a stop-cock, while the magnets, which can easily be taken out, are from time to time removed, cleaned, and then replaced. When the preparation of a glaze is completed, it will be in the form of :—

(i) A *slip* weighing 24 to 32 oz. per pint, according to its composition and the manner in which it is to be applied.

(ii) A *jelly*, which is made by preparing a glaze-slip in the ordinary manner, but with rather less water than usual, dissolving about 5 per cent of gelatin in the remaining (hot) water, and adding this to the slip, which will solidify when cool.

(iii) A *dust* which may be sprinkled or blown on to the ware.

Which of these forms is the most suitable depends chiefly on the ware and the manner in which it is desired to apply the glaze.

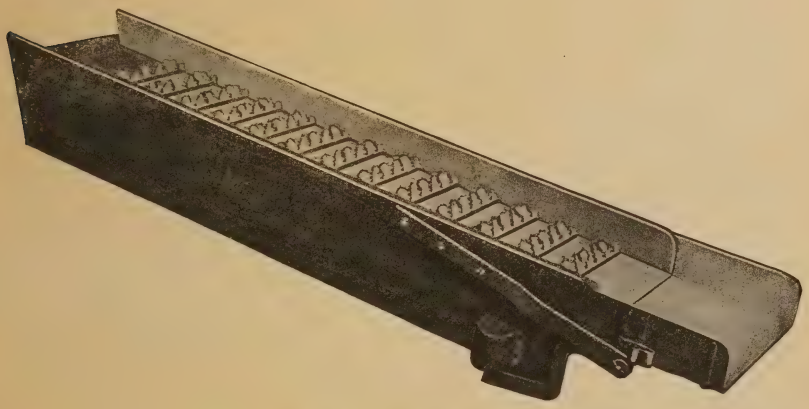


Fig. 118B.—Electro-magnetic glaze-purifier (Magnetic Separator, Ltd.).

Application of Glazes.—A glaze may be applied to ware which is (i) in the leather-hard or half-dry state, (ii) completely dry, (iii) in the biscuit state, and (iv) glazed, though this last is unusual. In the first two cases the ware must be sufficiently resistant not to be spoilt either by the actual application or by the dampness of the glaze. In the third case, the articles to be glazed may have been fully burned at a temperature higher than that needed to cause the glaze to mature, or the ware may only have been heated to about 800° C., so as to make the application of the glaze easier. If glaze is to be applied to a previously glazed surface, the latter must usually be prepared by a coating of mastic or other " medium," which will enable the subsequent coat of glaze to adhere. The application of glaze is easiest when the ware is in the state of biscuit, as it is then sufficiently porous and absorbent to absorb the glaze and make it adhere.

Seven methods of applying glazes are used : Dipping or immersing, pouring, sifting or sprinkling, spraying, painting, dusting, and volatilization.

In applying a glaze by *dipping* or *immersion*, the article (preferably in the biscuit state) is dipped in a vessel containing the glaze-slip ; the article, in consequence of its porosity, absorbs some of the water from the slip, so that a thin layer of the solid portion of the glaze-slip is deposited on the surface of the ware. The thickness of the coating will depend on the porosity of the ware, the time of immersion, and the density of the slip. These can only be ascertained by trial. Care must be taken that, when the glaze has dried on the article, it is not in the form of a loose powder which is liable to drop off at the least touch. To avoid this defect the glaze should contain a small proportion of plastic clay (china clay or kaolin being generally used), but sometimes the presence of white lead or plaster of Paris renders that of clay unnecessary. For this reason, when a glaze is to be fritted, at least a portion of any clay in it should be kept back and only added to the ground frit. If, for some reason, clay cannot be used in a glaze, a little starch or gum (previously boiled in water) may be added, but is liable to cause other defects and is better avoided.

Before dipping an article, any dust on it must first be carefully removed ; the article is then held by the fingers by the parts that do not need to be covered with glaze. If there are no such parts, it is better to hold the article in an iron tool having pointed claws, so as only to leave small places on which the glaze is defective. These places can be touched afterwards with a brush filled with glaze-slip. For pieces that need care, retouching is inevitable. The parts on which there is too much glaze (as drops or streaks) are equalized either with the finger or a scraper ; some glaze is added to the edges (which generally get too little) with a brush, or it is removed from some parts (such as the feet, plinths, etc.), on which the piece ought to stand. Dipping is the most rapid and usually the most satisfactory method of applying a uniform coating of glaze, either to the exterior or interior (or to both). The interior of large articles is sometimes glazed by pouring in some of the slip, turning the article round so that the whole of the interior is covered, and then pouring out the surplus slip ; this is known as *rinsing*. By exercising sufficient care, different parts of an article can be coated with different glazes by the adroit use of dipping.

In *pouring*, the glaze is poured over the article, which is given a suitable motion to spread the glaze uniformly. The unused glaze falls into a receptacle over which the article is held. This method is employed when the glaze is to be put only on the inside or outside of a vessel. It is also used for those bodies which are not very porous and which, by dipping, would not retain a sufficiently thick layer. For this method the glaze ought to be made thicker than for dipping, and, if necessary, its viscosity should be increased with milk, starch, or gum ; these materials disappear in the burning. Any retouching is done in the same way as after dipping.

Sprinkling, which is scarcely ever used now, consists in sprinkling the objects with glaze-slip, which is applied either through a fine sieve or by dipping short, hard-haired brushes in the glaze and then dabbing them on to the article in a manner similar to that used when stencilling. This method was chiefly employed for unbaked

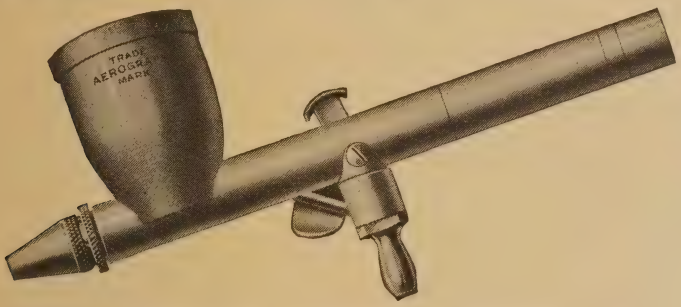


Fig. 119.—Aerograph for glaze-spraying (The Aerograph Co., Ltd.).

bodies which were friable or covered with reliefs and could not, without being spoilt, have been dipped or have glaze poured over them ; such articles are now sprayed.

Spraying or *diffusion* consists in applying a glaze-slip in the form of a fine spray by means of an *aerograph* or *sprayer* having two tubes at right angles, one of which is in contact with a reservoir of glaze-slip and the other is connected to a supply of air under pressure. The openings of the two pipes are so arranged that the current of air from one draws up the liquid in the other and forms a fine and well-diffused spray. For small objects, the pressure of the air may be created by means of an india-rubber ball ; for very large surfaces, an air compressor (Fig. 120) that can give a pressure of about 4 lb. per square inch should be used.

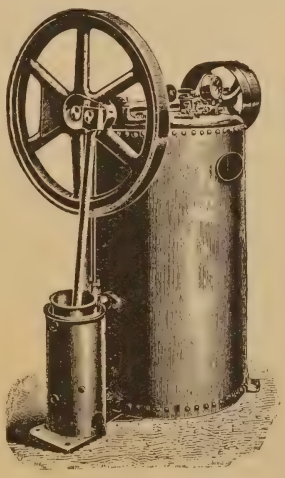


Fig. 120.—Air-compressor.

The nozzle or jet of the sprayer is placed 6 to 18 in. from the article, according to its size and the force of the spray, and either the sprayer or the article is moved, or both simultaneously, so as to spread the glaze uniformly over the surface. If a thick coating is desired, the whole thickness of it should not be put on at one time, but in two or more operations, allowing each layer to dry before putting on another. This prevents " trickling " and gives a coating of more even thickness.

Painting consists in applying the glaze by means of a brush in a manner similar to the application of paint to other articles. The glaze may be in the form of a slip, but better results are usually obtained if the glaze has been solidified by means of a gelatin (p. 183) In order to obtain a sufficient thickness of glaze, several coatings are usually required ; in applying glaze to some sanitary ware ten or even twelve separate coats are applied.

In *dusting*, the glaze is applied in the form of a fine dry powder to unfired articles which are still damp, so as to retain the glaze which is applied to them by means of a sieve or a " sand-blast." This method, which is now scarcely used except for coarse ware with a plumbiferous glaze, is very dangerous to the health of the workman, because of the dust, and should be avoided wherever possible.

Glazing by *volatilization* consists in volatilizing the glaze by heat in the kiln used for burning the ware, and insuring its deposit on the surface of the latter. As no glaze is volatile, what usually occurs is that one constituent is volatilized and deposited as described ; it then combines with the silica in the ware and thus forms a glaze. This method is only used in the manufacture of stoneware by what is known as *salt-glazing*.

CHAPTER VIII.

FIRING.

(1) Properties of Bodies and Glazes during Firing.

The firing is the last, the most important, and the most difficult operation in the manufacture of pottery. Its purpose is to make the body permanent, to give it resistance or impermeability, and to vitrify the glazes, by giving them the physical properties of glass.

The temperature to which a body must be raised to make it unchangeable depends on its chemical composition and on the fluxes it contains ; it varies from 700° to 1500° C. The temperature for vitrifying the glazes is still more variable and ranges between 500° and 1400° C, naturally, it must be below, or at the most equal to, that needed for the firing of the body ; when it is equal, the firing of both glaze and body may comprise a single operation ; when it is lower, the body must first be biscuited, then glazed, and later, by a second firing at a lower temperature, the glaze must be vitrified.

On principle, a single firing ought to be chosen, whenever possible, not only because of the economy, but also because the firing at the same temperature of both body and glaze makes their union more complete, giving to the ware certain special qualities of resistance. But it is necessary to resort to a double firing if it is intended to apply certain fusible glazes to a hard body, which can only be obtained at a higher temperature. There are commercial reasons why it is often better to fire twice even when the finishing temperature of the glaze and body are identical. One of the chief of these is the greater commercial value of some defective burned but unglazed articles than of those defective ones which have been glazed and fired simultaneously. There is also less damage to articles during glazing if these have been fired.

Numerous variations in the firing of bodies and glazes are made when convenient. For instance, hard porcelain is usually fired first at a very low temperature, so as to facilitate the adhesion of the glaze after dipping ; afterwards the ware is refired at a high temperature, at which both the body and glaze mature simultaneously.

Highly decorative ware is sometimes fired several times in succession, a different part of the decoration being applied just before each firing ; the temperature of each successive firing must be

lower than that of the previous ones, or the earlier decorations would be damaged.

The study of firing may be subdivided into three parts : (1) The effect of firing on the properties of the bodies and glazes ; (2) the kilns ; and (3) the methods of firing.

Effect of Firing on Bodies.—A piece of unglazed ware which has been dried and is ready to be fired still contain some hygroscopic water, which is evaporated at a temperature slightly above 100° C. in the first stage of the firing, this stage being called, rather unsuitably, *smoking* or *stoving*. At a slightly higher temperature the organic matters are deprived of their volatile elements, and the hydrated silica, iron oxide, and some alumino-silicates, such as allophane and collyrite, are decomposed.

As the temperature continues to rise it does not produce any further changes till nearly 400° C., when " pure clay " begins, in its turn, to decompose, as do halloysite, lenzinite, cymolite, talc, bauxite, magnesite, etc. ; this decomposition proceeds slowly as the temperature rises to 600° C. or above. The carbon in the organic matter then begins to burn by combining with the air in the kiln. At about 700° C. the body consists of an anhydrous mixture of free silica, crystalline silica, alumina, the oxides of iron, alkalies, carbonates of lime, and magnesia, and several silicates, including felspar, and analogous minerals and " grog." The other mineral substances which the body may contain are only found in proportions too insignificant to exert any influence on the firing. Below 700° C. all bodies act in the same way, their constituents remaining mixed without any fresh chemical combination with one another.

Above 700° C. the alkalies, then the oxides of iron (if in sufficient proportions and in the presence of alumina), begin to unite with the free silica to form various silicates. Any single one of these bases could not at this temperature combine with the silica ; they can only act when mixed. Hence, in bodies which only contain a small amount of fluxes, silicates do not begin to form until a higher temperature is reached.

At about 780° C. the carbonates begin to decompose, carbon dioxide is given off, and the bases are set at liberty, and with alumina and other fluxes, unite with the free silica, forming new silicates, which are more complex, so that at a temperature of about 900° C. different bodies show considerable variations in their constitution ; it then becomes necessary to divide them into four sub-divisions :—

(1) *Bodies containing a large proportion of fluxes, but not much crystalline silica, or in which the latter is only found in the form of an impalpable powder.*—In these bodies nearly all the bases are combined with silica, though some of the carbonates are not decomposed. The crystalline silica has been attacked in its turn and disappears in the fused silicates. The bases and the alumina, being entirely combined, the baking may be considered finished near 900° C. If the raising of the temperature is continued, the mass

softens, rapidly gets out of shape, and melts to a dark coloured, blackish-brown or green slag, which tends to be swollen by bubbles, which are formed by the carbon dioxide arising from the decomposition of the carbonates.

(2) *Bodies containing a large proportion of fluxes and having an important amount of crystalline silica in grains of a fairly large size.*—In these bodies nearly all the bases are equally united with any amorphous or impalpably fine free silica, but the crystalline silica remains intact, and forms in the mass of fused silicates a sort of rigid skeleton. The burning of these bodies also is finished, or nearly so, at 900° C. If the temperature rises further, the silicates begin to soften and to melt, but the mass keeps its shape, thanks to the unchanged crystalline silica. It is only at a temperature of 1100° to 1200°, or sometimes even higher, if the proportion of the fluxes is small, that the crystalline silica is attacked in its turn and the mass becomes misshapen and melts to a slag.

(3) *Bodies containing a small proportion of fluxes, the quantity of crystalline silica being slight or in an imperceptibly fine form.*—In these bodies the formation of silicates has scarcely begun at 900° C., the temperature must be raised to nearly 1200° before the alumina and the small amount of the flux will combine with the silica. This combination occurs more easily if the proportion of silica is high, without, however, passing certain limits. The mass vitrifies at various temperatures, according to the proportion of the fluxes.

(4) *Bodies containing little flux, but a large proportion of crystalline silica in coarse grains.*—As in the preceding body, the combination of the silica and alumina only takes place at about 1200° C. But at higher temperatures the mass vitrifies without softening, owing to its silicious skeleton. When there is only 1 or 2 per cent of fluxes, the body is only melted at the highest temperature that can be produced in the ceramic industry.

It is well understood that these four classes of body are not clearly distinguished, and that some wares have all the intermediate characteristics, but in a general way it may be considered that the *firing, properly so called*, of a pottery-product is finished when all the bases, and especially the alumina, are combined with silica. If the temperature is raised above this point in firing, either the body softens again, becoming misshapen, and ends by melting to form a slag, or else the body vitrifies without losing its shape, but at a still higher temperature it melts like a more fusible mixture. When sufficient molten material is formed to fill the pores in the body with a glassy material (thus making it impermeable) the body is said to be *vitrified*, and the rise in temperature which occurs during this period is termed the *range of vitrification*.

The Parts played by the Different Materials in Bodies with regard to their Fusibility.—In a glaze each constituent may play a double part, inasmuch as it has its own individual fusing-point, and it may, by combining with other substances, produce a fresh one which is more easily fused than either of the separate materials.

Alumina ought to be considered as the chief refractory element in all pottery products, but Cobb has found it is a flux in some glazes.

Fluxes.—Included under this head are potash, soda, ferrous oxide, lime, magnesia, and lead oxide. Each of these fluxes taken alone only combines with silica at a high temperature. But a mixture of equal parts of potash and soda is more fusible than either the potash or soda alone ; a mixture of potash, soda, and iron oxide is more fusible than the alkalies alone, and so on. The precise cause of this singular action is still unknown.

The relative fusibility of the five chief fluxes, according to Richter, is proportional to their chemical equivalents, that is to say, that 47 parts by weight of potash act as 36 of iron oxide, 31 of soda, 28 of lime, and 20 of magnesia. This statement, which seems correct at high temperatures, is not so at low ones nor in presence of a high proportion of fluxes, because the temperature at which these different bases begin to act on the silica is not the same. When the particles are all of the same size, the alkalies combine first ; then comes the lower oxide of iron (FeO). The order of the other fluxes is not yet fully determined. Ferric oxide is not a flux ; it acts as a refractory material, although to a less degree than alumina unless (as often happens) it is reduced during the firing.

Silica plays a complex part because, according to circumstances, it can either increase or diminish the fusibility. Pure silica is very refractory, consequently when some silica remains uncombined in a body, it reduces the fusibility. If bases and silica are both present at a sufficiently high temperature, silicates are formed which fuse more easily. From these observations, the parts played by the silica may be briefly stated :—

At a relatively low temperature, below 1000° or 1100°, only the free amorphous or colloidal silica, or the crystalline silica in an impalpable powder, can combine with the bases and so increase the fusibility. At a higher temperature, the crystalline silica is converted into another form, which appears to combine more readily with any bases present, and so helps to increase the fusibility so that the alumina remains the only refractory material. If, however, the proportion of the silica is large enough, there will be more than sufficient to neutralize the bases, and some silica will remain uncombined ; this excess of silica acts as a refractory, as opposed to the silicates with which it is mixed.

These facts about silica and alumina and their effect on the fusibility are more clearly shown when mixtures of the two substances in the pure state are heated to very high temperatures without the presence of any fluxes. As long as the proportion of alumina is higher than that contained in pure clay, the mixture is almost infusible ; the fusibility increases at the same time as the proportion of silica, until the composition corresponds to $Al_2O_3 16SiO_2$; mixtures with more silica are more refactory.

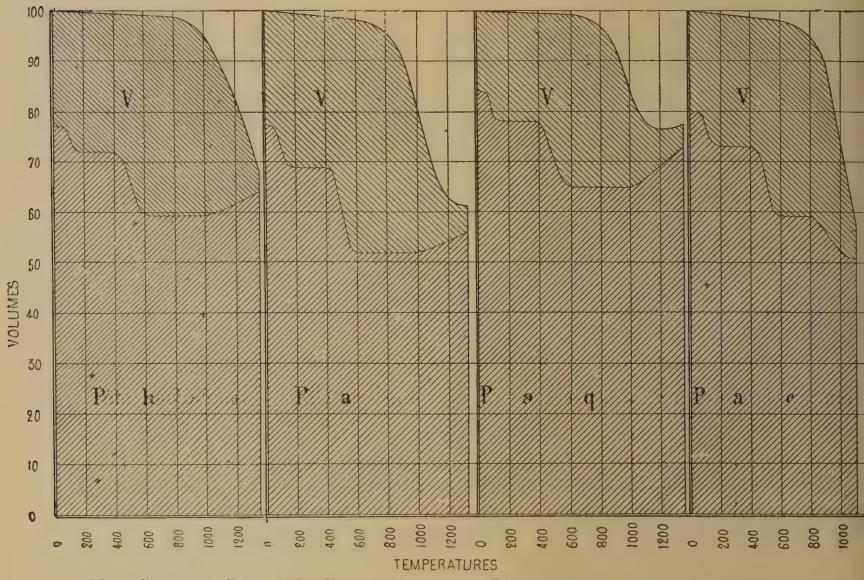
Grog, having the same composition as the body (p. 40), acts as

a refractory constituent at temperatures below that required for vitrification, but from the moment it softens (at the same time as the body) it has no influence on the fusibility.

Effect of Firing on the Volume and Density of Bodies.—The evaporation of the moisture from an almost dry body causes a diminution in the density of the body, because the shrinkage, if there is any, through that means is very slight, and is not made up by the increase of empty pores. The evolution of the water of combination acts in the same manner, and up to about 600° to 700° C. the volume of the body slightly decreases, while the density becomes continually less. But from the moment when the silicates begin to form, the body contracts and tends to fill up the empty pores made by the evaporation of the water and by the burning of the organic matter. This shrinkage proceeds regularly until the commencement of vitrification, when the pores tend to disappear, the body becomes impermeable and the apparent density attains its maximum. The shrinkage is at first constant, rather low and nearly proportional to the temperature, until the latter corresponds to the finish of the firing of the body. After that (i.e. with overheating), the shrinkage increases fairly quickly, and becomes more rapid as the temperature of fusion is approached. Some bodies, however, show remarkable variations in their behaviour on firing, due to the variable proportion of water (both hygroscopic and combined), to the shrinkage of kaolins and of other clays not taking place at the same temperature, and, finally, to considerable variations in the volume, caused by a high percentage of quartz or carbonates. These changes are graphically represented (Fig. 121), the variations in the total volume and those in the pores of four typical bodies being shown.

The first type is that of the *kaolin* bodies (china clays). The total volume of the dry body (taken as 100) diminishes very slowly and very slightly with increasing temperature until about 800° C. Above that temperature the shrinkage increases more and more quickly to about 1350° to 1375°, i.e. the temperature for burning hard porcelain. The volume of pores in the dry body increases quickly at first between 50° to 130° C., on account of the evaporation of the hygroscopic water, then remains nearly constant, and between 400° and 600° C. it again increases rapidly on account of the decomposition of the alumino-silicic acid (clay). The volume of pores lessens between 600° C. and 800° C., first because of the shrinkage, and afterwards because the body, above about 1000° C., decreases in absolute density. This reduction of porosity is due to the formation of silicates, which are the least dense when they have been produced at the highest temperature. When a state of equilibrium has been reached as regards the formation of silicates, and the heating is continued, a simultaneous reduction of the volume and the density of the body occurs. Fig. 121 shows that this is due to the reduction of pores which hides the expansion of the body, its weight remaining constant, while its density diminishes.

All the natural silicates—felspars, granites, porphyry, etc.—undergo a reduction of density when they are heated to a temperature near that of their fusing-point. Thus, for a kaolin body, the absolute density of the powdered body is at first about 2·4, and increases in consequence of the giving off of water to nearly 2·7, but on further heating it diminishes again to about 2·5. The apparent density (the weight of unit volume) starts at 1·6 to 1·7, diminishes regularly during the evaporation of the water, but increases rapidly afterwards as the pores become filled with molten matter. The apparent density never becomes equal to the absolute density, because even in those bodies which are completely vitrified there are always some pores.



V = Spaces. Pk = Kaolin paste. Pa = Plastic paste. P a q = Silicious paste. P a c = Calcareous paste.

Fig. 121.—Variations in volume on heating.

Plastic bodies of nearly pure clay differ from the kaolins just described in the larger proportion of water (*a*) because the shrinkage is nearly complete about 1200° C., and (*b*) because, after that, the volume only diminishes very slowly. This last difference, unexplained up to the present, is very characteristic, and distinguishes the plastic clays from the kaolins (china clays).

Silicious Pastes.—When the bodies contain a notable proportion of quartz, the expansion which the latter undergoes in passing from quartz with a density of 2·7 to cristobalite with a density of 2·2 (to which attention has already been drawn) is added to that of the clay, and the reduction of the pores is often insufficient to hide it. This

is the case represented in the third type in Fig. 121, in which the volume of the body having diminished at 400° to 600° C. remains constant to 1000° C., and afterwards increases. This behaviour can easily be noticed in fire-bricks rich in silica.

Calcareous Pastes.—In bodies with a sufficiently high proportion of carbonates the elimination of carbon dioxide above 800° makes a third increase in pores, as shown in the fourth part of Fig. 121. As these bodies are usually fusible, the shrinkage continues up to the fusing-point, this sometimes occurring before the evolution of the carbon dioxide is complete.

From the foregoing it will be seen that each body, when fired, undergoes characteristic changes in several important properties—particularly infusibility, volume, porosity, and density—a study of which will often give a very large amount of information concerning the body and its behaviour.

Effect of Firing on the Colour of Bodies.—Of all the different substances which enter into the normal composition of ceramic bodies, only the compounds of iron and organic materials have colouring power.

Other substances which are coloured when heated in bodies (such as the oxides of manganese, titanium, vanadium, copper, and chromium) are normally present in such exceedingly small proportions that their colouring power is negligible. If such substances are deliberately added in a suitable proportion to a body their colouring power must be considered (see *Decoration*).

Bodies coloured by *organic matter* are almost black when in the moist state; on drying they become grey, and during the firing the organic matter first chars and blackens and then burns away, unless the ware is heated too rapidly so that the surface is vitrified and the carbon in the interior cannot oxidize.

Under normal conditions, the fired body will be white with a pure clay, grey in the presence of manganese, and a deep greyish-blue when there is a sufficiency of titanic acid. Vanadic acid produces a yellow or green efflorescence.

Iron is usually the only colouring element in a body, the different oxides giving shades varying from greenish-blue to black, from yellow to orange or red, and from yellowish brown to green, under *oxidizing conditions*. The study of the conditions under which these different combinations can be produced is one of the most complex in ceramics.

Whatever may be the form in which iron is found in plastic bodies, it is changed into red iron oxide when heated in an *oxidizing* atmosphere. If the body only contains a small proportion of lime or magnesia the colour varies from cream to yellow or buff, then to orange and finally to red, according to the proportion of iron oxide it contains. Five per cent of iron oxide is sufficient to give a clear red, which reaches the maximum of intensity when 8 or 9 per cent is present, the colouring not being changed by larger proportions. It has been repeatedly found, however, that the colour does not

bear any definite relation to the proportion of iron present. As the temperature of the firing is raised, the red shade deepens and tends to pass into brown, owing to the formation of a brown double silicate. When a body contains lime or magnesia, and the temperature of the kiln remains about 800°, the colour due to the iron remains the same as in the absence of lime, but if it exceeds this temperature a complex silicate is formed which is yellowish when the proportion of lime or magnesia is double that of the iron oxide. In other words, these two bases neutralize the colouring of an amount of iron oxide equal to half their weight. Thus, a body containing 10 per cent of lime or magnesia and 7 per cent of iron has about the same colour, when fired, as a body free from lime and containing only 2 per cent of iron oxide. If the temperature continues to rise, the silicates of lime and iron take a greenish-yellow tint, which becomes quite green at the moment of fusing. When the kiln gases contain sulphurous fumes, these combine, in the form of sulphuric anhydride, with the lime in the body to form calcium sulphate; the lime thus combined can no longer enter into the formation of the multiple silicates, and loses its property of decolouring the iron oxide. As this action is only produced on those surfaces of the ware which are exposed to the fire-gases, it follows that some wares have a red colour externally, while the interior, which is more protected, is yellow or greenish-yellow, characteristic of double silicates of lime and iron.

Under *reducing conditions*, on the contrary, i.e. if the atmosphere no longer contains any oxygen, but rather an excess of hydrogen or of carbonic oxide, the red iron peroxide (Fe_2O_3) is changed into monoxide (FeO) and gives rise to new colours. If in small proportion, the compounds of ferrous oxide have a light bluish tinge, such as may be seen in most porcelains. If the proportion increases, the colour deepens rapidly and passes into black with blue metallic reflections. The presence of lime or magnesia does not alter these colours nor have sulphurous fumes any action in a reducing atmosphere, because they remain in the form of sulphurous acid.

The atmosphere in a kiln may be *alternately oxidizing and reducing*, especially at high temperatures; the degree of oxidation of the compounds of iron may then be modified several times during the process of firing, but the final colour is that which corresponds to the composition of the atmosphere at the commencement of cooling. If this, as nearly always is the case, is oxidizing, the repeated changes in the kiln atmosphere have the effect of diminishing the intensity of the colour which would have been produced if the atmosphere had been wholly oxidising throughout.

The oxidation or reduction of the iron oxides can only be produced in a porous body, which allows the combustion gases to penetrate it. If the burning is carried to a temperature high enough to cause vitrification, or if the body is covered with a glaze, it will retain the colour corresponding to the composition of the atmosphere at the time of its vitrification or of the fusion of the

glaze. This fact is of enormous importance in the manufacture of porcelain and stoneware, because it allows the burner to give the body the bluish colour of the ferrous silicate by working under reducing conditions during the principal firing, but with an oxidizing atmosphere during the cooling.

In thick or dense bodies, changes in the composition of the atmosphere can only act at the centre of the article after sufficient time has been allowed for the gases to penetrate to the centre of the ware. This often requires a very long time. Thus, in some articles the iron in the centre may be in a state of (black) monoxide, and on the surface in the form of (red) peroxide. The contrary case, although more rare, is also known. It is only very seldom that the reducing action of the kiln-atmosphere is so intense and prolonged as to cause a complete reduction of the oxides of iron into metallic iron. But if the cooling of a porous body is effected in an atmosphere charged with hydrocarbons, these decompose when heated to red heat ; the hydrogen combines with the small amount of oxygen contained in the atmosphere of the kiln, and the carbon is deposited in the pores of the body, making it grey or black. This property is sometimes used to obtain black or blue-black terra-cottas. If such an article is heated a second time to redness in an oxidizing atmosphere it becomes discoloured, and takes a reddish tint unless, during the previous heating, the pores nearest the surface have been sealed with fused matter.

Defects in Bodies due to Firing.—Many defects in various kinds of ware appear in the firing, but they may have an earlier origin ; the principal ones are :—

(1) *Defects arising from the moulding* (*pressing*) have been mentioned in Chapter V ; they consist chiefly in the articles getting out of shape on account of differences in density, or as the result of an unequal pressure on the body during the moulding.

(2) *Defects due to a bad charging or setting of the kiln* are described in the sections relating to setting.

(3) *Defects arising from too low or too high a temperature in firing.*—With porous bodies, too low a firing temperature makes the ware too tender, insufficiently resistant when in use and on exposure to weather ; with bodies intended to be impervious, vitrification remains incomplete and the ware is porous. An excess of heat, on the contrary, distorts the goods, or scorifies and then melts them.

(4) *Defects arising from too rapid a heating*, such as those due to the formation of steam in the interior of the mass, which may make the ware crack or even burst. A body which has been completely dried can be heated more rapidly, but as it is difficult to heat all the parts of an article equally, variations may occur in the shrinkage, and may cause breakages which might be avoided by heating it sufficiently slowly and regularly at first.

(5) *Defects arising from too rapid cooling* may be occasioned either during the cooling after burning, or by the sudden admission of cold air to the ware during the burning. In both cases cracks or dunts are produced.

(6) *Defects due to a wrong composition of the atmosphere in the kilns* are shown by an irregular colouring, or one different from that desired (see p. 192). Coal smoke and hydrocarbons may cause a deposit of carbon in the interior of the pores of the body. In very porous wares this deposit is consumed during the last period of burning or the early stage of cooling, this being nearly always oxidizing, but in impervious wares carbonaceous matter may, on the contrary, remain sealed in the pores from the commencement of vitrification, and give a yellowish-smoky tinge which cannot be removed.

(7) *Defects arising from the presence of sulphurous fumes, or of acid fumes derived from the decomposition of some alkaline salts in the atmosphere in the kilns.* The fumes or acid combine with any lime in the body and often cause spots or scum on those parts of the articles which are exposed to the gases. In non-calcareous pastes, and with a reducing atmosphere, sulphurous fumes have no noxious action.

The ashes of the fuel always contain alkaline salts, which may be carried by the kiln-draught and fall on the surface of the ware, causing the formation of fusible silicates. At the beginning of the firing, when the kiln is still damp, these salts, with any soluble salts naturally present in the body, may form a *scum*.

(8) *Defects arising from soluble salts contained in the body* are not due to the burning, but to the composition of the body ; they are mentioned here, however, because they do not become clearly visible until the ware has been removed from the oven. These soluble salts (sulphates, chlorides, and some silicates of lime, soda, potash, and magnesia) dissolve in the water in the moist ware, and during the drying they pass with it from the centre to the surface of the ware, and form a whitish efflorescence. When the products of combustion contain sulphurous fumes the sulphuric acid formed from them unites with the bases of the soluble salts, yielding sulphates and forming white spots on the ware. If the ware is heated sufficiently these salts may be decomposed by any free silica present and fusible silicates formed ; such molten silicates form a slight, scarcely visible glaze, but otherwise do no harm. If, however, the firing temperature is not sufficient to convert the soluble salts into silicates fresh quantities may be dissolved and brought to the surface whenever the ware is moistened—as by exposure to rain—and so they are able to form new efflorescences even after several months. These, being soluble in water, can be removed by simple washing.

Salts of vanadium also produce yellow and green efflorescences. This defect is noticed principally with some clays associated with lignite, which are very much used in North Germany. Such efflorescences, when yellow, are produced when the burned ware is exposed to damp, yellow vanadic acid being formed ; under the influence of the coal dust a bluish-green colour is produced, because of the reduction of the vanadic acid to oxide of vanadium.

(9) *Defects arising from the lime and magnesia compounds con-*

tained in the body forming "peas" of lime or caustic magnesia; these—by becoming hydrated and increasing in volume—cause the ware to split. This defect may be prevented by plunging the ware into water directly the ware comes out of the kiln.

Firing Glazes.—A glaze may be applied to a body which is simply dried, or to one which has previously been fired. In the first case, the precautions necessary to obtain a perfect firing of the body are usually sufficient to insure the successful firing of the glaze. In the second case, the operation is much easier; the temperature may be rapidly raised to the point at which the glaze begins to vitrify, as it is only from the moment at which the glaze is changed into glass that its properties are noticeably different from those of the body.

For each composition of the glaze there is a corresponding temperature at which it begins to soften, this depending on the manner in which its constituents combine to form silicates and borates. As the molten glaze becomes hotter and more fluid, it spreads equally over the surface of the body in the form of a viscous adhesive layer. If the temperature continues to rise, the fluidity would become sufficient to destroy the adhesion of the glaze to the body, and it would run towards the lowest parts of the ware. Hence, the temperature for firing glazes is confined between very narrow limits, and it is necessary to proceed so that the liquefaction shall not take place too suddenly, but shall be preceded by a fairly long period in which the glaze is molten, but highly viscous. When the vitreous layer is spread uniformly, the temperature is kept constant for a period of time which varies with the nature of the ware, then it is allowed to fall regularly and slowly enough to prevent some of the defects mentioned in the preceding section. Excessively slow cooling at first should be avoided, as it tends to cause crystallisation and devitrification of the glaze.

The chief defects of glazes after being fired may be divided into four classes :—

(1) *Defects arising from the non-adhesion of the glaze* because the surface of the body is too compact, dusty, or greasy. The result, after firing, is fissures in the vitreous layer, which seems to contract more than the body.

(2) *Defects arising from the body being too absorbent* so that the molten glaze penetrates into the pores and may be completely absorbed by them. The same effect may often be seen when glazed ware is placed in kilns by the side of pieces of porous ware which are not glazed, as, for example, the saggars which are used in charging, or the walls of the kiln. In this case, there is a partial volatilization of the glaze, which is carried on to the unglazed bodies.

(3) *Defects which are the result of too low or too high a temperature in burning.*—In the first, the vitrification is incomplete, and the glaze has the appearance which is characterized by the name of *egg-shell*. In the second, the too fluid glaze runs towards the lower

parts of the ware, leaving the others bare. This defect of *trickling* or *running* is also produced when the coating of glaze is too thick for it to be entirely retained by the adhesion of the body. Too high a temperature of firing may also cause a *boiling* of the glaze, which then, on cooling, shows many *bubbles* or *blisters*.

(4) *Defects in the composition of the body of the glaze* may cause the glaze to contain *bubbles* or be dotted with numerous little blackish points. The cause of this defect is a gaseous decomposition of the glaze (the giving off of carbon dioxide, oxygen, etc.) or a chemical reaction between the elements of the body and those of the glaze.

Agreement between Bodies and Glazes.—If the burning and glazing are completed in a single operation it is necessary that there be *an agreement between the temperatures for firing* the body and the glaze. This is generally arranged by varying the proportion of the refractory elements or of the fluxes, in either the body or the glaze or in both simultaneously. This problem does not occur when the burning is in two operations, the first being the firing of the body, and the second, at a lower temperature, that of the glaze ; yet, no matter what process of firing is adopted, the moment the glaze is spread as a molten glass on the surface of the body, they both become united, and (like all solid bodies) expand under the influence of heat, and return to their original size when cooled. Hence, during the cooling *the contraction of the body and that of the glaze must be the same*. If the glaze contracts more than the body, it will be subjected to a tension which may cause its rupture, either in connection with the cooling, or later as the result of an external cause (concussion, heating, etc.). This breaking usually takes the form of numerous cracks, and is known as *crazing*. The nearer together or the more numerous these cracks, the greater the antagonism between the body and the glaze. Sometimes, when the glaze is very thick, this defect may become serious enough to cause the body itself to break. If, on the contrary, the glaze contracts less than the body, it is compressed, and if this compression passes the limit of its elasticity, the glaze breaks, forming chips, which are detached from the body, sometimes taking portions of it with them. This defect, which is the opposite of crazing, is known as *scaling* or *peeling*.

The problem of obtaining perfect agreement between the contraction of a body and that of a glaze is one of the most difficult met in ceramics. It can only be solved by a series of trials, and the difficulties which beset the ancient potters—who did not know the exact compositions of bodies and glazes, such as are given by chemical analysis, and who were ignorant even of the cause of their failures—were often insurmountable to them. One of the quickest methods of securing the requisite agreement consists in determining the exact composition of the body and the glaze and then firing trial pieces. If these show crazing, the composition of the glaze is modified by reducing the proportion of alkali and increasing that of the silica or the boracic acid, as these make compounds that expand the most ;

oxide of lead occupies a middle place, while the compounds of alumina, lime, and magnesia have the least expansion. On the other hand, the monosilicates have a greater expansion than the bisilicates. Boracic acid gives compounds which act like the bisilicates. When, on the contrary, the trial pieces are scaled, the composition of the glaze is modified in the opposite way. Generally, after a few failures, the desired result is obtained. If, however, such is not the case, the composition of the body must be modified, and a new series of trials begun.

When *crazing* occurs, the following modifications should be tried with the body :—

(1) Increase the proportion of silica.
(2) Grind the body more finely.
(3) In non-vitrified bodies increase the amount of the fluxes.
(4) In vitrified bodies reduce the amount of the fluxes.
(5) In bodies containing ball-clay and china-clay, increase the proportion of ball-clay and reduce that of the china-clay.

If, on the contrary, there is *scaling*, the reverse modifications are made.

Silica has a much greater expansion than clay, and its addition to a body tends to reduce crazing and to increase scaling, especially if the grains are very fine. Hence crazing may be reduced by grinding the silica more finely, or, on the contrary, the scaling may be reduced by using coarser grains of silica.

The action of the *colouring oxides* is mentioned in Chapter IX, which treats of Decoration.

The *fluxes* affect the temperature needed for firing the body. In non-vitrified bodies, the expansion rapidly increases as the firing temperature rises. The result is that in melting a glaze on three specimens of the same body, one slightly, the second medium, and the third very highly fired, if the firing temperature of the glaze agrees with the second specimen, the first specimen will craze and the third one will be scaled. In this case, an increase in the amount of fluxes acts like the raising of the temperature, i.e. it reduces crazing and increases scaling. Vitrified bodies in which the expansion diminishes, on the contrary, change more and more into a glassy mass, and an increase of fluxes causes crazing and reduces scaling. Bodies which are not vitrified but are rich in silica act in the same way ; their expansion, after having reached the maximum, is reduced on a further raising of the temperature. This fact can be explained by the progressive change of silica (quartz) with a density of 2·6 to 2·7 into silica (cristobalite or tridymite) with a density of 2·2 to 2·3, the denser form having a greater expansion than the other.

The foregoing suggestions show the line to be followed in securing an agreement between bodies and glazes, but they equally show the difficulties as well as the perseverance and skill needed for producing high-class ware.

Fusibility and Firing Tests.—In starting a new pottery or endeavouring to produce new kinds of ware, colours or glazes, many tests or *trials* are required, and it is, therefore, desirable, if not essential, to have a test-kiln, which will allow of a high temperature being readily obtained and modified so as to give at pleasure an oxidizing, neutral, or reducing atmosphere. The fuel usually employed in test-kilns is either charcoal, illuminating gas, or electricity. With the former, for temperatures not exceeding 1000° C., one of the furnaces used in chemical laboratories may be used, but for higher temperatures an air-blast is necessary. For trials on vitreous ware and for glazes, satisfactory results are only obtained by heating with gas.

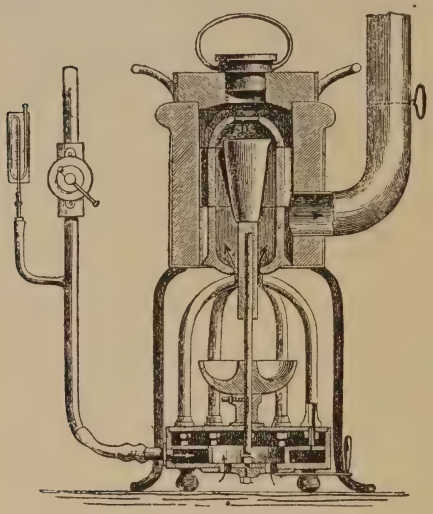


Fig. 122.—Test-kiln.

Fig. 122 shows an apparatus, designed by Perrot, which easily gives any temperature up to 1300° C. The gas enters by a lower ring, from which it passes up a series of tubes placed circularly, drawing a certain quantity of air with it. The flames from the ends of the tubes penetrate to the centre of the kiln, pass up around the crucible or the piece to be heated, then descend again nearer the outside walls of the kiln and escape by the chimney, as shown by the arrows. This kiln is constructed with six, nine, twelve, and even twenty burner-tubes.

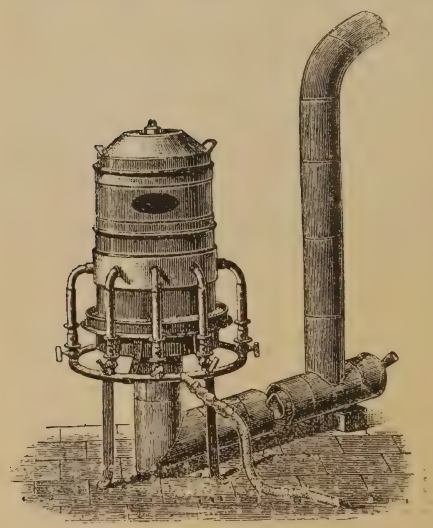


Fig. 123.—Test-kiln.

A more useful kiln is shown in Figs. 123 and 124; it easily allows the test-pieces to be heated to the temperature required for burning firebricks or hard porcelain. The gas is led in through a circular pipe A to a series of burners B, while the

air enters at C into an horizontal tube, rises vertically, and then enters the kiln at D. The combustion takes place at F, and the flames first rise and then descend around the pieces to be burned, which are placed upon a little table F. Thence they continue to descend, and the products of combustion enter the pipe G, where they warm the air, and escape to the chimney. The contents of the kiln are easily seen by opening the little plug H, and the supplies of air and gas are adjusted accordingly.

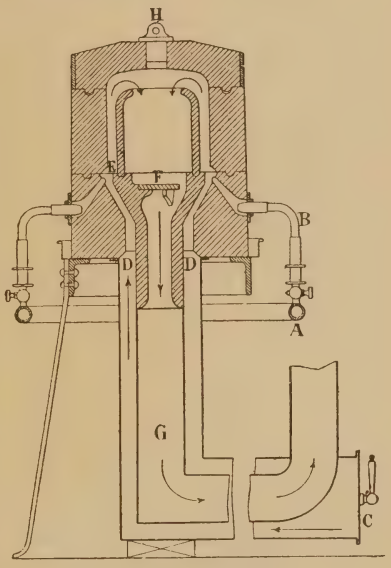


Fig. 124.—Test-kiln.

An electrically heated furnace is often more convenient where electricity is available, and enables tests of the refractoriness of highly resistant materials to be made with greater certainty and convenience. Trials of fusibility are made with pieces of body, shaped like little bricks, or tall pyramids.[1] For trials of impervious ware, or of glazes, slabs or plaques from 2 to 10 in. square, and $\frac{1}{8}$ to $\frac{1}{2}$ in. thick, or " 3 in. tiles " are used. It is always wise to try two or three pieces at a time, because of accidents in firing, which it is not always easy to avoid. The temperature is measured by means of a pyrometer (described later).

(2) Fuel.

As in other industries, the first fuel used in pottery was *wood*, and though in the course of the last century it has been almost entirely replaced by *coal*, wood is still used in certain districts, and has several advantages for burning wares in which the expense of fuel is only a small part of their total value. *Lignite*, *peat*, and occasionally other vegetable materials such as *grass* and *straw*, mineral *oils*, *natural* and *producer-gas*, are also used.

On account of the distance between the fire-box and the articles to be fired, a long-flaming fuel must be employed, and it is only in exceptional cases and during the commencement of the firing that a short-flamed fuel can be used. Dry fuel which contain very little cinder is preferable to an inferior fuel with much ash. For very high temperatures (above 1150° C.), fat coal, open burning coal, or producer-gas produced from inferior coal may be used.

[1] The most suitable shape is a tetrahedron, i.e. a piece having a triangular base and three sides meeting in an apex; seger cones (p. 248) are of this shape.

Wood is used in the forms of logs and faggots, but sawdust can only be used when mixed with coal. The hard woods—oak, beech, elm, ash—give more heat than birch, fir, pine, larch, poplar, and aspen, but produce a shorter flame. The lighter woods last named give off long flames and are usually better for burning coarse pottery, but cannot be used for the production of the higher temperatures required for stoneware, porcelain, and refractory materials. For burning bodies, fir, pine, and larch are generally preferred, and for burning glazes, birch, beech, or ash are used.

Coal is classed under five heads, according to the proportion of volatile matter in it, and the manner in which it behaves during combustion :—

(1) *Anthracite* and short-flaming sandy coals, which can only be employed in gas-producers and for the production of medium temperatures.

(2) *Open-burning coals*, which can only be used in direct contact with the bricks or other articles to be fired.

(3) *Fat coals*, *smithy coal*, or *blacksmith's coal*, which give a bulky coke, and can only be used when mixed with close-burning coal (sandy coal) on account of their tendency to cake.

(4) *Gas coals*, when they do not cake, are specially suitable for heating kilns needing long flames and attaining a high temperature.

(5) *Sandy coals* with long flames, giving an open, non-caking coke, are largely used for baking pottery, but give lower temperatures than the preceding ones.

The proportion of ash is rarely below 2 per cent, and may reach 25 or 30 per cent, the average being 5 to 15 per cent. Ash not only diminishes the heating power of the coal, but also hinders combustion by forming clinker, filling the grates, and make frequent cleaning necessary. It is advisable, in the manufacture of fine ware and for obtaining the higher temperatures, to use coals of better quality than those often employed, or producer-gas may be made from a lower grade of fuel if it contains a sufficiently large proportion of coal. For ware of less value, and fired at a low temperature (800° to 1100° C.), it is often possible to use coals of inferior quality, but it is only by actual trial that the most economical fuel for any particular case can be ascertained.

Coke is very useful at the commencement of the burning, because of its regular combustion, but it cannot be used when long flames are necessary. It may sometimes be mixed with fat coal.

Lignite and *peat* of good quality are suitable for pottery which is to be fired at moderate temperatures. They should be as dry as possible.

Grasses and *straw* have been used, in the absence of other fuels, for burning common bricks.

Natural gas is used in America but not in Europe.

Mineral oils have also been employed in the United States and in the Caucasus, but are not much used outside the countries where they are produced. The great advantages of such oils are their

heating power, the great control which is possible when they are used, and the simplicity of the mechanism used to burn them. In most countries oil is, at present, much more expensive than coal per ton of ware produced, but an increase in the price of coal might make oil a preferable fuel, as it is already in some countries where coal is very costly and oil is available.

The effective value of a fuel can only be determined by actual trial, but the fire-boxes must be adapted to it. The calorific power of a fuel is interesting, but is not conclusive for industrial purposes. If there is a danger that the use of an unknown fuel may spoil the burning, it is easy to mix it in increasing quantities with the fuel ordinarily used. It is useful, when comparing coals, to determine the proportion of ash, and of the material volatile at a good red heat.

(3) Kilns and Ovens for Firing Ware, etc.

All kilns and ovens are for the dual purpose of producing and utilizing heat. The production of heat is effected by one or more fire boxes and the means for creating the draught, including the arrangements used for introducing the fuel into the kiln, mixing it with air, and thus ensuring its combustion.

The chimney or other means for creating the draught apparatus ensures the introduction of air and creates the circulation of the gases and flames in the interior of the kiln. The heat is utilized in one or more "chambers" in which the flames or hot gases are brought into contact with the goods or with the saggars or other receptacles in which the goods have been placed. To these parts—which are all essential—it is convenient, whenever possible, to add another, namely, some means of making use of the heat contained in the "waste" kiln-gases instead of allowing it to escape up the chimney. The chief means of recovering this so-called "waste heat" are (i) by *recuperators* or *regenerators*, which transfer the greater part of the heat to the air entering the kilns and used for the combustion of the fuel; and (ii) by passing the waste gases from one oven or chamber into others, so as gradually to heat up the contents of the latter before allowing the gases to enter the chimney. For the most effective utilization of the heat, the kiln must work continuously.

The kilns and ovens at present used in the ceramic industries are of several different types, according to the variety of wares and the differences in the temperatures needed for burning them. In selecting a kiln, all the arrangements of it must be studied for the special manufacture in view, the nature of the fuel, the various properties of the bodies, glazes, and other materials, and the general necessities of the manufacture. It is only by satisfying in some measure these many conditions that a kiln can work efficiently and economically.

Fireplaces.—In order that the heating power of the fuel may be used to the best advantage, the fuel must be burned or gasified in

suitable fireplaces. These must be constructed in accordance with the requirements of the fuel and with the nature of the flame or hot gases needed in firing the ware. For these purposes, four kinds of fireplaces (including gas-producers) are used :—

The combustion of the fuel in the midst of the ware can only be used in the manufacture of bricks, etc., which are not harmed by contact with ashes or flame. This method of heating is, in theory, the most economical, because it uses the heat as soon as it is liberated, and should be preferred to all others whenever it can be used.

Combustion of the fuel on grates is suitable for burning all kinds of pottery, bricks, and other ceramic materials. The fuel is spread uniformly on the surface of the grate (which may be of cast iron or fireclay), sufficient air being allowed to pass up between the bars so as to insure complete combustion. For very high temperatures such fireplaces are inconvenient ; they get dirty, are difficult to clean, and the grates quickly wear out.

Combustion in furnace-fireplaces is common in the pottery industry. The fuel is used in a thick layer, the fireplaces may have either a hearth or a grate. Such fireplaces are sometimes known as " half-gas producers," being intermediate between ordinary grates and true gas generators. In such a furnace there are usually four zones of decomposition of the fuel—one in which the distillation of the fuel takes place ; another in which coke is formed ; a third in which the coke is converted into gas ; and the fourth in which the gas is burned. The shape of the fireplace can easily be modified to suit special needs and does not present any particular difficulty. The air required for the production of gas and the combustion of the fuel is usually supplied through several air inlets, which can be regulated at will. These fireboxes or semi-producers are very suitable for the production of high temperatures, but are more difficult to regulate for slow firing. The fuels used are logs of wood, long-flamed coal, coking coal or coke.

Gas producers are special fireplaces in which the fuel is converted into gas, which is led into the kiln through pipes or flues to burners, where it is mixed with air and ignited, producing flames of the nature required. The management of kilns heated by gas is remarkably easy, and such gas is suitable for all methods of working and for all temperatures, but the conversion of fuel into gas naturally involves a loss of heat, which must be compensated by other advantages, or the gas will prove to be too costly.

Primary and Secondary Air.—In semi-gas producers and gas-producers it is necessary to have two different supplies of air :—

(i) The *primary air* enters through the grate and passes through the fuel ; it is chiefly converted into carbon *mon*-oxide (CO), which is a combustible gas.

(ii) The *secondary air* is usually heated by passing it through flues in the side-walls of the fireplace, or through a recuperator or regenerator. Its chief purpose is to burn the gas produced by the action of the primary air on the fuel.

The great advantage of separating the air into two parts in this manner is that the combustion of the fuel is under much better control. Various positions of the inlets for secondary air are shown in Figs. 133-135. In a gas-fired kiln, the air entering the producer is primary air ; that used to burn the gas is the secondary air.

Fireplaces for Wood.—Wood can be burnt among the goods or ware when they are not injured by contact with the ashes. This method of heating presents no difficulty other than that resulting from frequently putting wood into the kiln, which causes the entrance of cold air and a serious loss of heat—defects which are specially noticeable when faggots are used ; to remedy them the openings or *mouths* for charging should be lengthened outwardly to the shape shown in Fig. 125, the mouths being closed by a sheet-iron plate, as shown. These mouths should hold so much wood that any air drawn in by the draught during charging is warmed before it reaches the contents of the kiln. This arrangement is used especially for faggot fuel ; it is equally applicable to intermittent kilns and to continuous kilns.

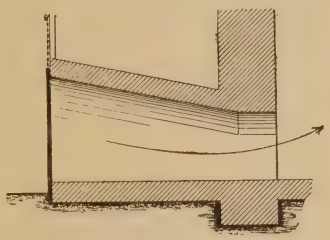


Fig. 125.—Furnace mouth for wood.

Blocks of wood may also be burnt in fireplaces with grates as in Fig. 126. The hearth should be prolonged beyond the front of the kiln, and the wood charged through an upper opening ; the

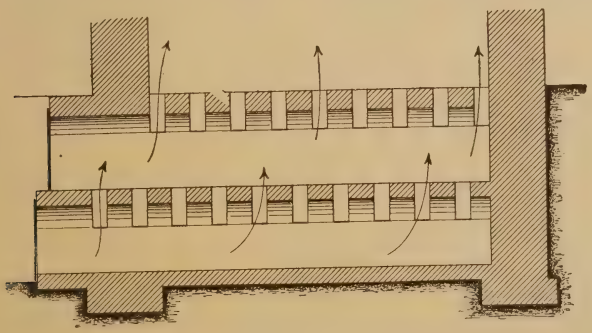


Fig. 126.—Fireplace for burning wood.

flames pass upward through openings in the floor of the kiln—as shown by the upper arrows in Fig. 126, and the air for the combustion of the fuel enters—as shown by the lower arrows—through a lower passage which forms the ashpit. A part of the fuel falls into this ashpit and is consumed there while heating the air. This arrangement is specially applicable to up-draught kilns, and can easily be modified when necessary.

For the production of temperatures above 1150° C., various patterns of fireboxes are used. The type represented in Fig. 127 gives good results provided all the logs are of the same length. These are piled in the upper opening of the fireplace, and rest on two brickwork projections. The combustion takes place by the air passing between the logs, the flames following the direction shown by the upper arrow ; the embers which fall to the bottom of the fireplace help the burning, owing to the air entering through the ashpit door, as shown by the lower arrow. This type of fireplace is built into and forms part of the kilns : it gives very long flames, and is suitable for all kinds of ceramic articles. For slow firing, the logs must be replaced by faggots, and the upper opening may be closed with a damper.

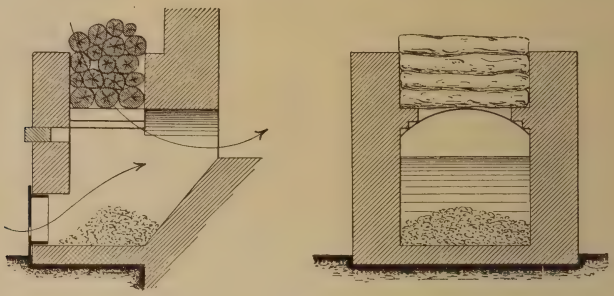


Fig. 127.—Fireplace for wood.

Fireplaces for Coal.—Coal may be burned in external fireplaces or by constructing special fireplaces of the articles to be heated. Thus common bricks may be fired by filling the kilns with alternating layers of bricks and fuel, as is done in lime burning. This method, which is used in England and Flanders, is described, on account of its special characteristics, in the paragraph on the manufacture of clamp bricks (p. 303). The contact of the fuel with the ware and the necessity of preventing the formation of cakes of coke make it preferable in this case, and as a solitary exception, to use rather sandy coal. In kilns with an horizontal draught the fuel can equally well be fed directly on to the ware, which is arranged so as to make a series of fireplaces, each composed of a number of *pillars* or *steps*. In A (Fig. 128), each fireplace is a kind of well or hollow pillar in which bricks project at intervals and keep back part of the fuel thrown in through the top, the feed-holes or pots being provided with covers. These pillars are 28 in. to 60 in. apart. In B, the setting is arranged to leave a bay or wall, in which the bricks are set so as to make regular projections, and cross the empty space, forming stages or steps across the full width of the kiln. The small fuel used lodges on these stages and burns there in the current of warm air, which passes horizontally through the kiln. The charging should be done in small quantities, frequently, and at regular in-

tervals. As the ash cannot soil any of the objects except those forming the well or the bays, more delicate wares, such as tiles, paving tiles, etc., can be put in the other parts of the kiln. An open-burning coal is generally used, but wood is equally good; a

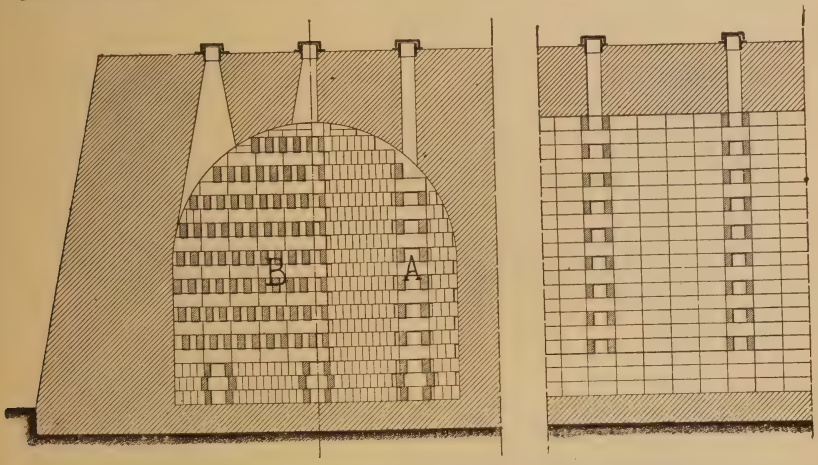


Fig. 128.—Two arrangements for burning coal among the goods.

space is left in the position ordinarily occupied by the projecting bricks, but the latter are not used.

Fireplaces with Grates which are placed either below or by the side of the kiln are largely used. When the grates are below the floor of the kiln they are usually narrow but very long. In Fig. 129

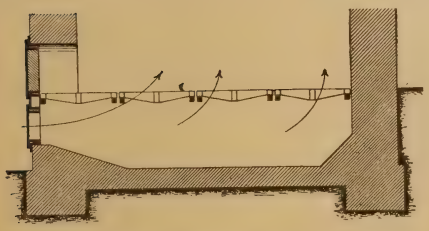


Fig. 129.—Fireplace with level grate.

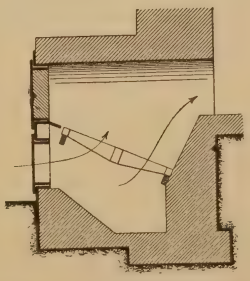


Fig. 130.—Fireplace with sloping grate.

the grate is placed on a level with the floor of the kiln, but it could equally well be covered with a perforated arch (see Fig. 126). The fuel is fed through a door placed at one end, or the coal may be thrown on to the grate through one or more openings in the top of the kiln, somewhat similar to those shown in Fig. 128. In both cases, the air enters through the ashpit. If, on the contrary, the

fires are at the side of the kiln, it is preferable to make the grate inclined, so as to be able to push the coke more easily towards the back and to put the fresh fuel near the charging door (Fig. 130).

The grates are usually made of metal, but fireclay bars are used in some kilns ; the size depends on the nature of the fuel. Moving grates or mechanical stokers are seldom used, as the heating being intermittent it is usually possible with good fuel to prevent the blocking up of the grate during the burning, and the fuel consumption per hour is usually much too small to make a mechnical stoker remunerative unless the coal is very poor in quality, when a mechanical grate (Fig. 131) is sometimes an advantage. The fronts of the fireplaces should be very solidly built ; sometimes they may be omitted or replaced by plates of sheet-iron which simply lean against the openings used for charging and emptying the ashpit.

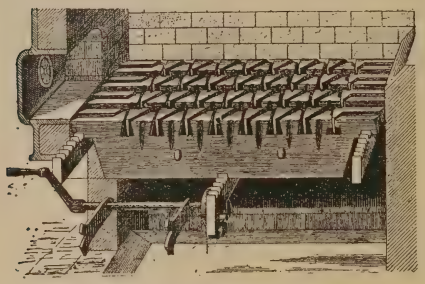
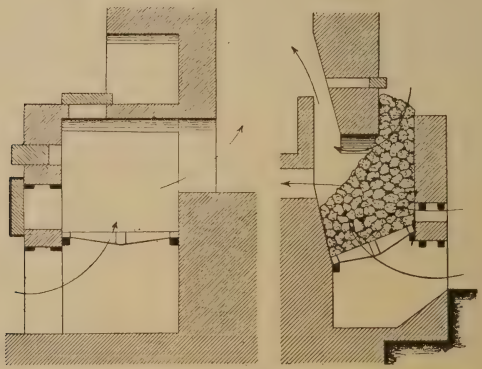


Fig. 131.—Mechanical grate.

Fireboxes or semi-producers resemble fireplaces with grates, on which is a very thick layer of fuel (Fig. 132). The door at the



Figs. 132, 133.—Kiln fireboxes.

front, on the level of the grate, is only used for cleaning purposes, the ashpit is partially closed by an iron sheet, and an opening between that for charging and the door for cleaning allows of an extra supply of air. This firebox is very suitable for slow firing, but in full firing the fresh fuel falling on to the burning coke causes irregularities in the combustion. This is avoided in the fire-box shown in Fig. 133, which is used for continuous charging. The

fresh fuel distils in the upper part, while the coke is burnt by the air coming in through the cleaning door and through the grate. The flames pass out of the fireplace by two openings, one vertical and the other horizontal, but this arrangement is a detail, and a single exit, as in Fig. 132, is often sufficient.

In modern kilns the tendency is to get farther and farther away from the grate-fireplace with a shallow bed of fuel, and to approach the gas generator. Fig. 134 shows a recent type of firebox in which the sloping grate is suspended at its upper end, and has, at its lower end, between it and the brickwork, a space through which the ashes and rubbish fall into the ashpit, from which it is easy to remove them. As in Fig. 133, the fuel distils in the upper part, and the coke burns in contact with the air which comes in through the grate. There is an extra supply of air (*secondary air*) entering on each side and heated by circulating through flues placed in the

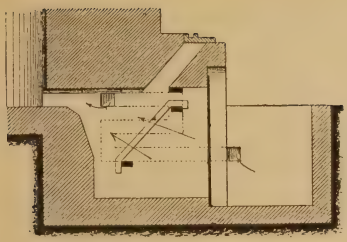


Fig. 134.—Firebox with secondary air-supply.

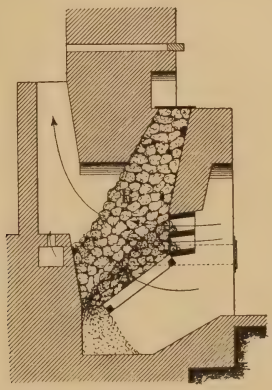


Fig. 135.—Firebox designed by E. Bourry.

side walls of the furnace. The charging door is usually closed. The cleaning is done easily and almost automatically by the descent of the fuel, or a rake may be passed between the bars. This fireplace gives very good results for full firing, and allows high grade fuel to be used, but does not lend itself to a prolonged slow firing, unless the area of the grate is reduced during the first portion of the burning by putting a fireclay slab on the sloping grate, and drawing it off gradually when a more intense heat is desired. In the fireplace shown in Fig. 135 the grate is vertical in one part and sloping in the other. During the slow firing, the former is closed by fire-bricks, and the fuel forms a thin layer, A. Afterwards, the damper on the vertical grate is opened gradually so as to lead to the full firing with a thick layer, B, and a large amount of primary air.

There is a supplementary supply of warm (secondary) air above the fireplace, but this is seldom used, as most of the secondary air

required enters through a series of vertical openings near the base of the combustion chamber, as shown by the small arrow in Fig. 135.

Heating by gas necessitates the use of one or more gas-producers with a system of flues connecting them with the kiln, and a series of gas-burners, each of which provides for the burning of a suitable mixture of gas and air ; the burners are placed in the walls of the kiln.

The principal purpose of the gas-producer is to change the carbon of the coal into a combustible gas, the chief constituent of which is carbon *mon*-oxide (CO), 3 lb. of carbon combining with 4 lb. of oxygen to make 7 lb. of carbon mon-oxide. This gas, when it burns, is changed into carbon dioxide gas. Actually, producer-gas

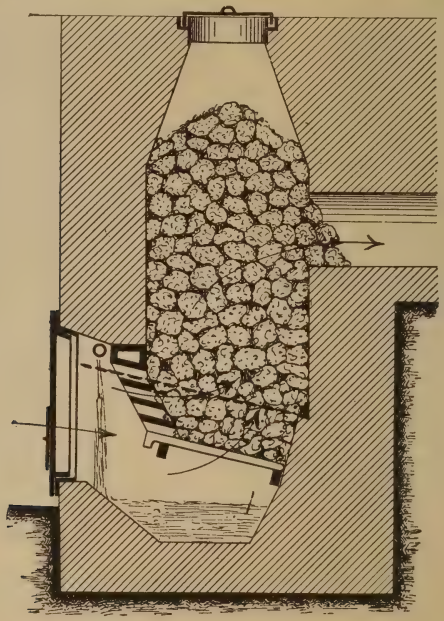


Fig. 136.—Gas-producer for non-caking fuel.

contains only about 20-28 per cent of carbon monoxide, the 45-55 per cent of nitrogen, also present, being derived from the atmosphere.

In the manufacture of producer-gas, the simultaneous formation of soot, clinker, and ash, which are very troublesome to remove, often cause a considerable loss of fuel, and grave irregularities in working. To this must be added the tendency of fat coal to cake and form a compact mass, which may completely stop the production of gas. These inconveniences disappear when anthracite, very sandy coal or coke is used as fuel, but these fuels usually produce gases which have too short a flame, and often too little heating power for pottery, so that it is necessary to use open-burning coal in order to obtain good results.

Two types of gas producer are used : (i) With natural draught, and (ii) with a blower. Exhaust producers in which it is necessary to cool and purify the gases before allowing them to pass into the gas-holder are of no use in firing pottery.

In *producers with natural draught*, the air is drawn in by the chimney draught, and by placing the producer sufficiently below the level of the burners to profit by the ascending force of the warm current of gas. In the producer shown in Fig. 136, the fuel is fed in through an upper opening, and fills a round, square, or rectangular chamber. The fuel rests on a stepped grating and on an ordinary

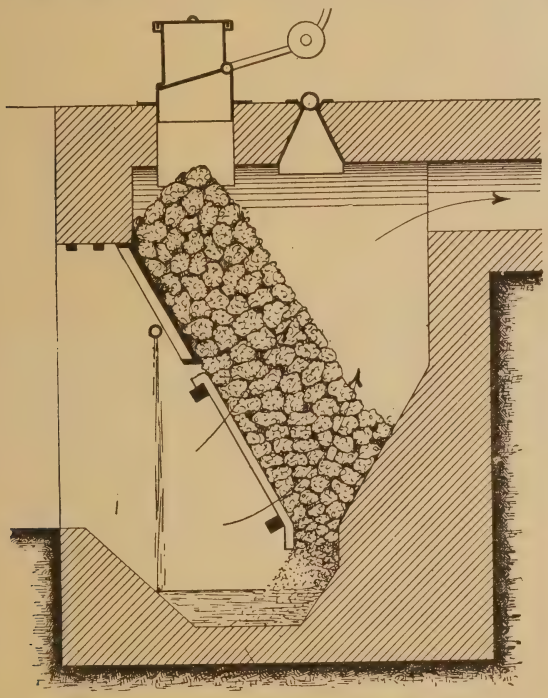


FIG. 137.—Gas-producer for caking fuel.

grate slightly inclined. The gases escape through a side opening, as shown by the arrow. A pipe pierced with small holes allows water to trickle constantly into the ashpit, which is closed by a door with an opening that can be regulated at will, allowing the introduction of air. During the cleaning of the grate a movable grate with round and pointed bars is sometimes inserted, and takes the position shown by the dotted line in Fig. 136 ; it rests on the last step in the grating and on a projection in the masonry.

The " fixed " grate is then raised, the rubbish and clinker are drawn out and fall into the ashpit. The " fixed " grate is then

replaced, and the movable grate taken out. This cleaning is repeated every four to twelve hours. Fresh fuel is supplied to the upper part of the producer as required, the bed being poked and kept level in the interval between two charges.

For fat and caking fuels this arrangement would not be suitable, and that shown in Fig. 137 should be used. A special hopper, arranged to prevent the gas escaping, is used for charging. The fuel falls on an inclined plate when the volatile matter distils off; the coke then passes on to a steeply sloping grate, where the carbon is changed into carbon monoxide. The ashes are easily removed by means of a hook passed between the bars or descend into the ashpit through a space left between the lower end of the grate and

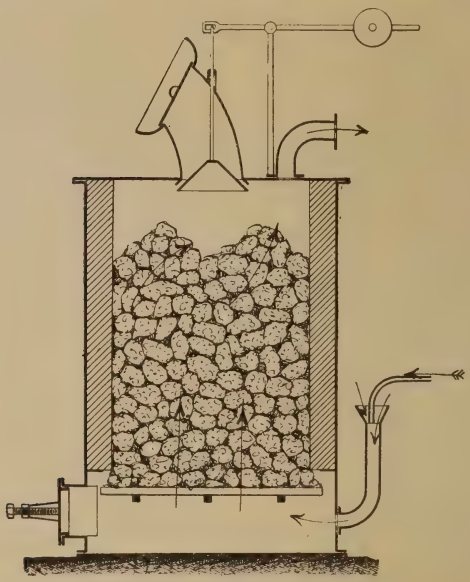


FIG. 138.—Gas-producer with air-blast.

the masonry. An upper opening, closed with an iron ball, allows of poking the fuel and of breaking the pieces which have caked together. Lastly, an arrangement similar to that in the preceding figure serves for supplying water to the ashpit. These gas producers are usually made without doors.

In *pressure gas-producers*, the air is introduced by pressure, either by means of a fan or an injector. They have the advantage over those with natural draught of allowing the pressure, and also the production of gas, to be regulated at will independently of the draught from the chimney; this is often valuable in working the kiln. The fan must usually be driven by a separate engine, but an injector only needs a small auxiliary boiler, which is easily worked by the kiln fireman, so that the latter is simpler, less costly, and also

furnishes the gas producer with the steam necessary for its most efficient working.

The air-blast can be adapted to both the types of producer just described, provided the door of the ashpit can be hermetically closed. It is, however, preferable to make the producers cylindrical in shape, and to place them on the ground level. For coke, anthracite, or sandy coal, an arrangement like that shown in Fig. 138 may be used, the fuel being introduced through an upper hopper with a bell or with double doors, and resting on a horizontal or an A-shaped grate, under which is injected a current of air and steam. The gas produced passes out through a pipe placed at the upper end of the producer. The ashes, etc., are cleaned out every six hours through one or two lower doors. This type of gas generator is particularly suitable to the production of short-flame such as is used for the production of motive power, but it needs to be worked very carefully when used for firing bricks, tiles, or pottery, as, for these, it is usually necessary to use a bituminous coal which produces a large amount of soot and necessitates frequent cleaning of the gas-ducts.

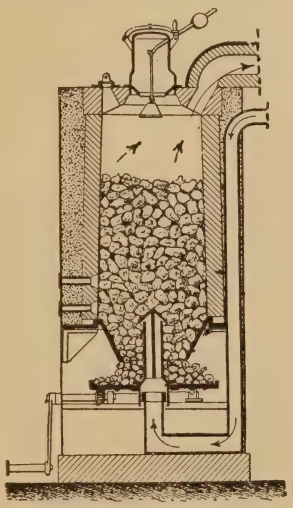


Fig. 139.—Taylor's gas-producer.

Many attempts have been made to facilitate the working of gas-producers and make them as automatic as possible. This is usually effected by means of automatic hoppers, ash-discharging devices (Fig. 139), and mechanical stirrers. So far, most manufacturers of ceramic materials have found that the simpler types of hand-operated producers are the best for their purpose.

The gas used in kilns for bricks, pottery, etc., need not be purified or stored in gasometers. The gas-ducts which join the gas generators to the kilns may therefore be very simple. They may be laid underground and made of brickwork, or metallic pipes in the open air may be arranged—lined inside with fire-brick masonry. In all cases, the gas-ducts should be air-tight and fairly non-conductive, so as to prevent undue cooling of the gas. When the gas-producers are working slowly with rich fuels, tar and soot are deposited in the ducts, and are removed from time to time by drawing air through them.

The burning of the gas in the kilns takes place at the fire-brick *burners*, which divide the gas into small streams and ensure it mixing with the necessary *secondary air*.

Draught may be natural or forced. *Natural draught* is created by a chimney, and is due to the difference in weight of equal volumes of atmospheric air and of kiln or furnace gases. The weight of

1 cub. metre of gas at temperature t is equal to its weight at 0° C. divided by $1 + at$, a being the coefficient of expansion of gases (= 0·00366). In this connexion, the differences of pressure, which are always negligible in kilns, may be neglected and a uniform pressure of 760 mm. or 30 in. of mercury assumed. If, then, a chimney 10 metres high, 1 metre square, internally contains air at (say) 200° C., the weight of a cubic metre of air at 0° C. being 1·3 kilogramme, the weight of this column of air of 10 metres at this temperature will be

$$\frac{1{\cdot}3}{1 + (0{\cdot}00366 \times 200)} \times 10 = 7{\cdot}5 \text{ kg.}$$

The weight of a similar column of air at 0° C. would be 13 kilogrammes. If there is a vertical opening 1 metre square at the base of the chimney, the layer of air there supports, on the outer side, a weight equal to the pressure of the atmosphere, measured at the upper part of the chimney, 13 kilogrammes, while on the inner side it only supports a weight equal to the same pressure, 7·5 kilogrammes. There is, thus, a difference in weight of 5·5 kilogrammes or 0·55 gramme per square centimetre, which displaces this layer of air and forces it to rise in the chimney. Similarly, if a chimney is 30 ft. high, 3 ft. square internally, and contains air at 450° F., the weight of 1 cub. ft. of air at 32° F. being 0·077 lb., the weight of the air in the chimney at 450° F. will be :—

$$30 \times \frac{0{\cdot}077 \times 492}{450 + 460} = 1{\cdot}248 \text{ lb.}$$

Indicating the height of a chimney by H feet, the gas at temperature t of weight d pounds per cubic foot at 32° F., while the atmospheric air of a weight δ per cubic foot is at a temperature θ, and a the coefficient of expansion (= 0·00366), the difference in weight at the base of the chimney of section S will be given by the formula

$$\frac{\text{HS}\delta}{1 + a\theta} - \frac{\text{HS}d}{1 + at}.$$

On simplification, this becomes

$$-\left(\frac{492\delta}{\theta + 460} - \frac{492d}{t + 460}\right).$$

If e represents the height of a column of water expressed in inches of water, having for its base the section of the chimney which balances this difference in weight, the depression caused by this chimney, measured in a column of water, is

$$e = -\left(\frac{0{\cdot}1919 \times 492\delta}{\theta + 460} - \frac{0{\cdot}1919 \times 492d}{t + 460}\right).$$

The difference between δ and d is so small that it may be neglected, and if $\delta = d = 0{\cdot}08$, then

$$e = -\left(\frac{7{\cdot}55}{\theta + 460} - \frac{7{\cdot}55}{t + 460}\right)$$

$$e = \frac{7{\cdot}55 -}{(\theta + 460)(t + 460)}.$$

On applying this equation to various temperatures it will be found that the draught e is proportional to the square root of the temperature.

This draught (e) should be sufficient to overcome all resistance (r) which the gas encounters in its passage through the kiln, and to give it a sufficient speed in the chimney not to be too much affected by the wind. The ascending motion is produced proportionately to $e - r$. The corresponding speed is given by the formula

$$v = \sqrt{\frac{(e - r)(1 + at)2g}{d}}.$$

It must not be less than 2 metres or 6 ft. 6 in. per second. Knowing t and r, the height, H, of the chimney may be calculated, and assuming that ($r = ae$), the volume of gas V delivered by the chimney in metric units is :—

$$V = S\sqrt{\frac{2gHa(1 - a)(t - \theta)}{1 + a\theta}}.$$

Summarizing, it may be concluded—

(1) That the draught produced by a chimney is proportional to its height and to the square root of the difference between the interior and the exterior temperature.

(2) That the volume of gas delivered by a chimney is proportional to the area and to the square root of its height and of the differences in the temperatures.

(3) That if in the preceding formulæ H = 1 metre, $\theta = 0°$ C., S = 1 square metre, the following quantities represent the draught, the volume, and the weight of air delivered in a second by a chimney 1 metre high and 1 square metre in section for the temperature t stated in the first column :—

Temperature. (t).	Draught. (e).	Volume (V).	Weight. (P).
Deg. Cent.	Millimetres.	Cub. Metres.	Kilogrammes.
10	0·046	0·848	1·017
50	0·201	1·897	2·073
100	0·347	2·683	2·538
150	0·459	3·286	2·741
200	0·547	3·795	2·829
250	0·619	4·242	2·861
300	0·678	4·648	2·860
350	0·727	5·020	2·841
400	0·769	5·366	2·811
500	0·837	6·000	2·736
700	0·931	7·098	2·572
1000	1·016	8·485	2·349

The weight of the air (P) delivered by the above chimney is

$$\frac{1 + at}{Vd}.$$

It increases when the temperature of the chimney increases, till it attains a maximum, and afterwards decreases again. Practically, after $t = 150°$ C., P scarcely varies, and there is no object in exceeding that temperature in order to increase the weight of air delivered. On the other hand, the temperature must not fall below 50° C. or it would need very large chimneys, which would work badly, because they would be too dependent on atmospheric variations, and the excessive cooling of the gases might lead to the condensation of the steam which they contain. A temperature slightly above 150° C. is the one to be preferred.

Forced draught is created by a mechanical appliance such as a fan or steam injector. Fans are extensively used for continuous kilns, but are seldom employed for intermittent ones. Steam injectors and blowers are seldom suitable for use in ceramic kilns and ovens. The great advantages of a fan over a chimney are (i) greater draught; (ii) much steadier draught; (iii) greater ease in regulating the draught; (iv) independence of atmospheric conditions. On the other hand, fans are more liable to mechanical breakdowns than chimneys, and the simultaneous presence of sulphurous gas and water vapour tend to cause the formation of sulphuric acid, which at a sufficiently high temperature spoils the fans. In calculating the draught of a kiln it should be remembered that some parts of kilns act like chimneys, and tend to increase or diminish the draught; hence, the foregoing remarks and formulæ apply equally to them, the height H being the difference in level between the openings for the air and the escape of the gases. For example, in a kiln with a circulation represented by Fig. 140 the depression will be shown by

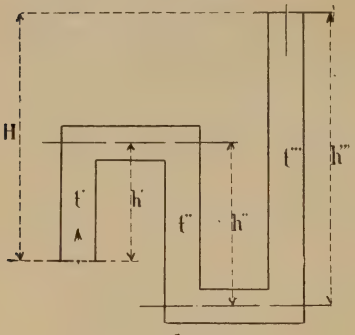


FIG. 140.

$$e = \frac{H\delta}{1 + a\theta} - \left(\frac{h'd}{1 + at'} - \frac{h''d}{1 + at''} + \frac{h'''d}{1 + at'''}\right),$$

the ascending parts increasing the depression or draught and the descending ones diminishing it.

If Fig. 141, in which the circulation is formed by an ascending current at temperature T, and by a descending one at temperature T', is examined, it will be seen that in a section on MN the difference of pressure is

$$\frac{hd}{1 + a\mathrm{T}} - \frac{hd}{1 + a\mathrm{T}'}.$$

If T is greater than T′, the motion of the gases is produced in the direction indicated by the arrows going from the current T to the current T′. In the contrary arrangement (Fig. 142) the same reasoning shows that the circulation is produced in the reverse manner, going from T′ to T. This may be expressed in another way, by saying that the draught is increased when the temperature of the ascending gases rises and that of the descending gases is lowered, and *vice versa*. It is not necessary that there should be a difference in level between the entrance for the air and the exit of the gases in order to set up a gaseous circulation in a kiln.

In the burning space, the movement of the flames and the gases may be ascending, descending, or horizontal. When this circulation is *ascending* (up-draught) it is necessary, in order that it may be regular, that the temperature should be absolutely uniform on each horizontal plane. If in any one place the temperature is raised, it tends to make a quicker circulation there and, consequently, to attract the flames there, so that the defect is more and more aggravated. Vertical currents which are very great and very hot (called

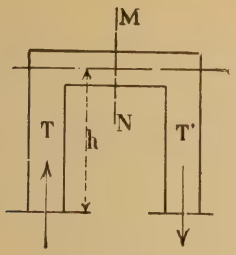


Fig. 141.

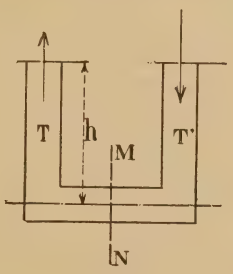


Fig. 142.

"chimneys") are then formed among the ware in the kiln. It is often very difficult to stop these and they may endanger the success of a firing. It is not the same when the circulation is descending (*down-draught*). If there is a rise in the temperature at one point, the draught becomes less, the flames are carried there less, until the evenness of the temperature which was interrupted for a moment is re-established. Thus the down-draught tends to make the temperature uniform after any irregularity caused by faulty working, while an up-draught, on the contrary, tends to aggravate the fault.

When the draught is *horizontal*, if the gases are hotter than the ware being fired, they tend to rise and flow along the top of the kiln; if, on the contrary, the gases are colder, they descend and circulate along the lower part of the kiln. Hence, in a horizontal draught, irregularities in temperature are likely to be aggravated. This may be avoided by increasing the resistance to the current in the upper part and diminishing it in the bottom of the kiln either by careful placing of the articles or by judicious stoking.

Draught-Regulation.—The regulation of the draught in the kilns

is for the purpose of varying the speed and the weight of the circulating gases. The regulation of the *speed* is necessary (i) to produce a good combustion in the furnace, because the speed ought to be between certain limits, which vary with the dimensions of the fuel and the thickness of the layer ; (ii) to make good use of the gaseous current, which ought to circulate slowly enough among the ware to transmit its heat to them. The *weight* of the gases, on the contrary, depends on the quantity of fuel consumed, and consequently on the intensity of the fire.

This double regulation is obtained by narrowing some parts of the kilns, and by putting openings of various sizes in other parts. At certain places also, air can be made to enter the kiln, especially between the fireplace and the burning space or combustion chamber, and between the latter and the chimney. The regulating openings are at the entrances of flues for air and at the exits of the gas ducts ; for this purpose valves with hinges, dampers, or other valves are used. The *clack valves* are placed at the top of the chimneys ; they are worked from below by a chain and a balance weight, and have scarcely any use other than to completely close the opening when the working of the kiln is stopped, because they are not suitable for an exact regulation of the draught.

When *dampers* are vertical, they are hung by a chain which passes over a roller and are balanced by a counterpoise. They should work easily, but do not close hermetically. In order to obtain hermetic sealing, horizontal or sloping dampers, which slide on their seat and are kept in place by their own weight, must be used. They may be of either cast-iron or firebrick, according to the heat to which they are to be subjected.

Gas-valves are usually round, and often conical in form. In order to allow of their closing hermetically they may be ground on the surface which comes in contact with the seat, or their edges may be dipped into a sand seal. They are lifted and lowered by a screw or a differential tackle or by hand. Such valves are made of cast iron, and though they form very good regulators for moderate temperatures, they do not last long when exposed to a great heat.

These various appliances, by varying the openings for the passage of the air, increase or diminish the volume of gas which circulates in the kiln, but do not act in the same way on the depression or draught. In the working of a periodic kiln, the temperature of which rises uniformly after the time when the gases passing into the chimney have reached a temperature of 150° C., the volume of gases passing out of the chimney is almost constant, but the draught keeps on increasing. If it needs reducing, so as to keep a regular working of the fire, it is often necessary to close the damper or valve to such an extent that the weight of gas given off becomes insufficient. Then a special opening at the side of the damper must be opened to allow a certain quantity of air to come in from the outside. This diminishes the weight of the gases given out, but acts in a much more efficient way on the draught. This inrush of cold air

has also the advantage of cooling the damper as well as the chimney, and, consequently, of preserving them from the action of too great a heat.

Classification of Kilns.—The terms *kiln* and *oven* are both used in a loose manner, although some potters attempt to make some distinction between them, referring to round kilns as "ovens" and rectangular ones as "kilns." In the present volume, both terms are used without any serious attempt at differentiation, the term *kiln* being generally preferred. In most brick and pottery kilns the heat is used direct, that is to say, the ware or the receptacles which contain it are directly exposed to the action of the flames and of the hot gases. In some kilns, called *muffle kilns*, the action is indirect, the flames heating the outside walls of the chambers without going inside them. The kilns of the first class are used for burning goods which are not spoilt by contact with the flames, and for those which need to be protected by special receptacles, known as *saggars*, and yet require to be burned at a high temperature. The muffle kilns are chiefly used for delicate ware which requires a moderate temperature for burning, but they are also regularly used for sanitary ware fired at 1300° C.

In these two classes of kilns the firing may be intermittent or continuous. If intermittent, there is usually only one burning chamber, but if continuous either the single chamber forms a continuous circuit or a series of chambers, also forming a circuit, is joined to one another.

For industrial purposes, it is convenient to classify kilns into seven divisions: (1) Intermittent kilns with up-draught; (2) intermittent kilns with down-draught; (3) horizontal intermittent kilns with one fire-hole; (4) continuous kilns with one burning space; (5) continuous kilns with several burning spaces; (6) horizontal intermittent kilns with several fire-holes; (7) muffle kilns.

Intermittent Kilns with Up-draught.—In olden times, the goods were simply placed in the middle of a brazier of wood, this method being used in making the large jars used by the ancients; it was impossible to move them far in an unburned state, and it was therefore necessary to bake them at the place where they were moulded. Even now a similar method is employed in burning ordinary bricks in clamps, made by piling up the bricks alternately with layers of coal or coke, as described in Chapter X. The first improvement on this type of kiln consisted in surrounding the ware with brickwork, the hollow interior of which formed the burning space; next, the fireplace was isolated, being placed under the chamber; later, the chamber or kiln was covered with an arch, several openings forming chimneys being arranged in this arch. The kiln shown in Fig. 143, was thus obtained, and for a long time it was the chief type of pottery kiln. It is still of service in localities where skilled kiln builders cannot be obtained, where fuel is cheap and the output limited. In Fig. 143, fireplaces suitable for heating with coal are shown, but fireplaces for heating with wood (Figs. 126 and 127) could

easily be adapted to it. Two side or end doorways, placed over one another and walled up during the burning, are used for filling and emptying the kiln. The openings for the exit of smoke, made in the arch, are covered more or less completely with terra-cotta slabs, which help to regulate the draught. It is wise to strengthen the kiln by means of vertical supports (termed *buckstays*) of wood or iron, fixed at their base in the ground, and joined at the top by iron bands passing over the kiln. The shape of the burning chamber may be square, rectangular, or circular.

A second type of intermittent kiln with up-draught is shown in Fig. 144. The burning chamber is circular, as this shape lends itself better to the uniform distribution of the heat. The kiln is heated by several fireplaces, spaced regularly on the outside of the kiln, the flames entering the burning chamber through openings in

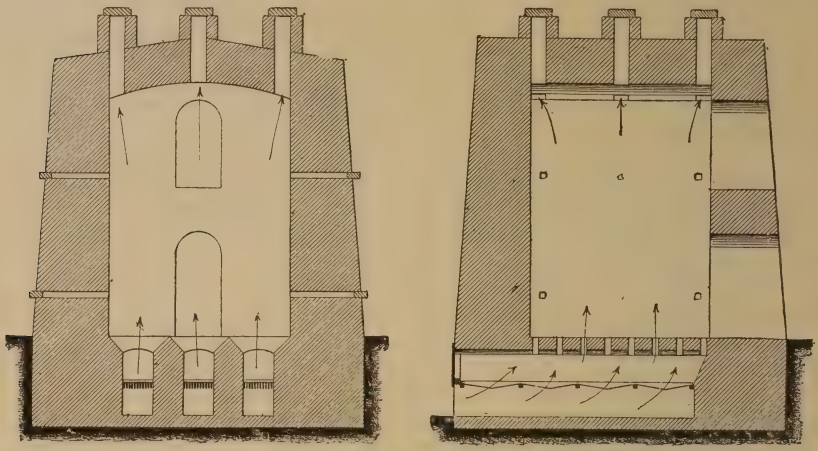


Fig. 143.—Rectangular up-draught kiln.

the walls known as *bags*, and through others in the floor or *sole*. The draught is regulated by openings arranged in the dome or crown, and the fuel is fed through one or two doors which are on a level with the floor of the kiln. Circular iron bands above the fire-holes, and particularly on a level with the springer of the crown, help to strengthen the kiln. This type of kiln is still frequently used, and at the time of its invention marked a great improvement in one of the principal stages in the history of pottery burning, yet apart from special cases, intermittent up-draught kilns should not be used, as they are wasteful and have an unequal distribution of heat; the same applies to square open kilns, round up-draught kilns with an upper story and other up-draught arrangements, which only deserve to be forgotten.

Intermittent kilns with down-draught are represented by four types :—

(*a*) Rectangular kilns ; (*b*) round kilns ; (*c*) round kilns with an upper dome ; and (*d*) round kilns with a lower dome. In all these kilns the heat is produced by fire-holes, for which, in certain cases, gas-burners can be substituted. The *rectangular kiln* shown in Fig. 145 can be built with a single independent chimney, or with a series of chimneys in the side-walls. The burning chamber, of rectangular form surmounted by a crown or arch, may be of any length, but for a great length the arrangement of separate chimneys is preferable, the draught not being so easy to regulate uniformly with a single

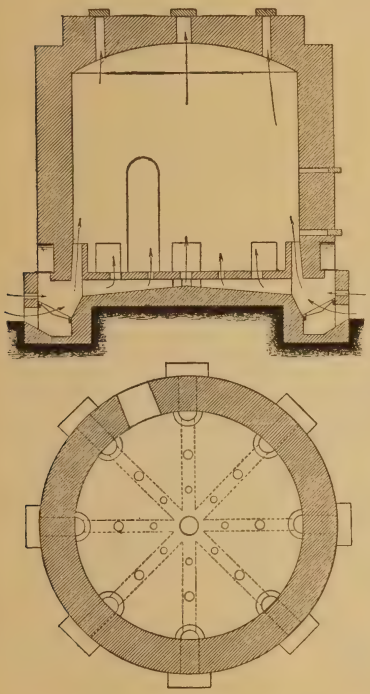


Fig. 144.—Round up-draught kiln.

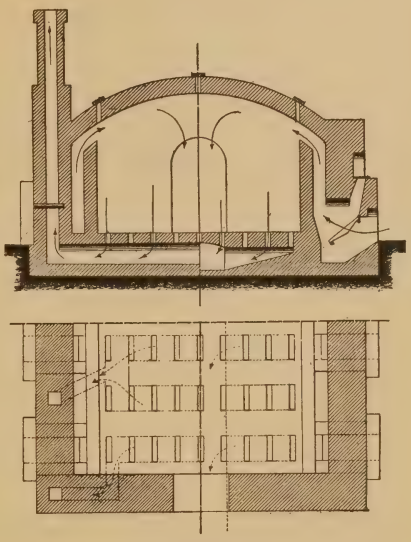


Fig. 145.—Rectangular down-draught kiln.

chimney. A door at each end is used for filling and emptying the kiln ; it is bricked up prior to commencing the burning. The kiln should be strengthened by *buckstays* on each side of the fireplaces, joined together by tie-rods above the kiln. Such a kiln is used for burning bricks and terra-cotta, the setting of which is more difficult in round chambers, but its employment should be strictly limited to articles which, for reasons explained in Chapter X, cannot be burned in continuous kilns.

The *round kiln* shown in Fig. 146 is built in various sizes according to the goods to be burned and to the temperature to be obtained.

The fireplaces, which number two to twelve, are placed regularly on the circumference of the kiln and about 6 ft. apart (centre to centre). When the diameter of the kiln is large, the fireplaces are united by flues beneath the floor, which join in one central inlet for the flames as shown in the figure. When, on the contrary, the diameter of the kiln is small, the direct entrance for the flames, through the *bag* behind each fireplace, will suffice. When the gases and flames have entered the kiln they rise, strike the crown and are

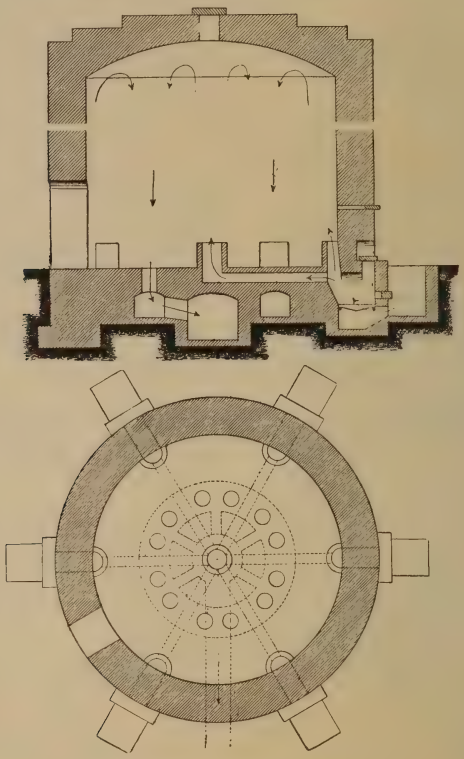


FIG. 146.—Round down-draught kiln.

reflected by it in a series of parallel streams to the floor of the kiln. If the shape of the crown is suitable, the reflected heat will be uniformly distributed over the whole area of the kiln. The gases, in passing downwards, circulate among the articles to be heated, raising them to the requisite temperature. The gases then pass out through openings in the floor, the arrangement, number, and dimensions of these depending on the goods to be burned and the method of placing them. All these openings lead into a central *well*, which communicates by an underground flue with an outside chimney,

which usually serves for several kilns. One or more openings in the crown of the kiln may be used for hastening the cooling after the burning is finished; one or more doors on the ground level allow the kiln to be filled or emptied. This kiln is specially used for burning pottery and stoneware; its working, although slightly better than that of round kilns with up-draught, is not all that could be desired, but when the kiln is properly filled the distribution of the heat is very satisfactory.

A *round kiln with an upper chamber* (Fig. 147) is used for burning

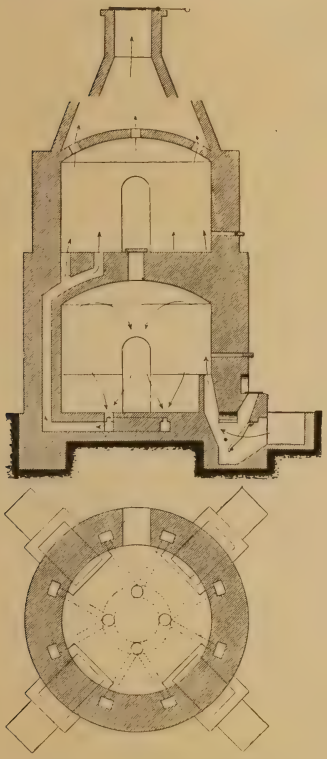


Fig. 147.—Round kiln with upper chamber (Minton).

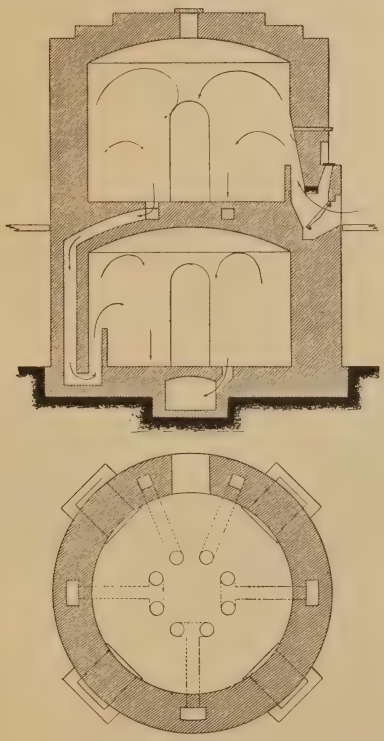


Fig. 148.—Round kiln with lower chamber.

pottery before receiving the glaze, such ware being heated in a second chamber by means of the flames rising out of the first. The working of the upper chamber is the same as that of the lower one, but the flames, instead of being united in a collector and passing thence into the chimney, rise through a series of vertical flues arranged in the walls, and then pass through several openings in the bottom of the upper chamber. They then continue to rise upwards through the upper crown of the kiln and into the cupola-chimney over the kiln.

Fig. 148 shows an arrangement of a kiln *with a lower chamber* in which the flames descend through the bottom of the upper chamber by flues in the walls to the lower chamber. There they rise towards the crown, then descend amongst the goods, and pass out by openings in the floor of the lower chamber, where they collect in a receiver and pass to an outside chimney.

In these two types of kilns with auxiliary chambers, the utilization of the heat is fairly good—slightly better in the second than in the first—in the former it is sometimes necessary to finish heating the upper chamber with supplementary fires. If heating by gas is adopted, it must be fitted to the kiln shown in Fig. 148, in preference to that shown in Fig. 147.

Connected down-draught kilns distribute the heat much better than those with up-draught, but the utilization of the heat, although generally better, is still imperfect. It is increased by heating with gas, which makes the kilns as economical as is possible with intermittent burning. It is convenient to use these kilns for burning all kinds of pottery needing a careful firing, for which continuous kilns are unsuitable.

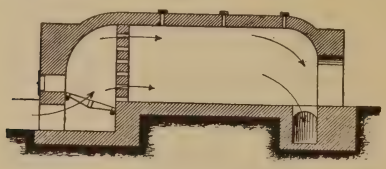


Fig. 149.—Cassel or Newcastle kiln.

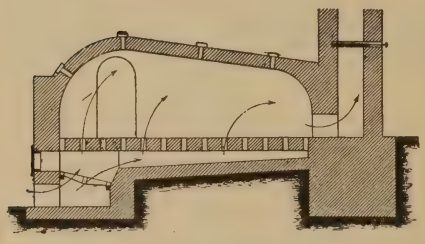


Fig. 150.—Modified Cassel kiln.

Horizontal intermittent kilns with a single fireplace are characterized by their shape and by a single fireplace at one end; the chimney is at the other. The types are numerous, but it will be sufficient to mention the three following :—

Fig. 149 shows a horizontal kiln of the *Newcastle kiln* type with flames that are exclusively horizontal; when several of these kilns are placed side by side, the draught is created by a single chimney which communicates with a smoke receiver, but if desired each kiln may have a separate chimney, as in the following examples.

Fig. 150 shows a kiln with flames which first ascend and are then horizontal.

Fig. 151 is a kiln with descending flames which are more or less oblique.

All the kilns of this class are inconvenient, because either the kiln is too short, the distribution of the heat fairly good but the utilization of it very bad, or else the kiln is too long, the utilization of the heat better, although still very moderate, but the distribution is very bad. Before the invention of round kilns they were frequently

used for high temperatures, but they are now unprofitable (except occasionally for firebricks) because of their fuel consumption which is high compared with that of continuous kilns.

Continuous kilns with a single firing chamber can be arranged in two very different ways : in the first the articles to be heated are piled on cars or trucks and travel in a continuous stream past fixed fireplaces ; in the second method, the fire is made to travel forward whilst the articles to be heated remain stationary. The first method constitutes what are known as *tunnel kilns ;* in these the goods, on a series of cars, enter a " tunnel " provided with a series of fireplaces or gas-burners on both sides of it, near the middle. The hot gases pass along the tunnel towards the end at which the goods enter, so that the goods are gradually heated as they pass towards the hottest part of the kiln. After having attained the maximum temperature

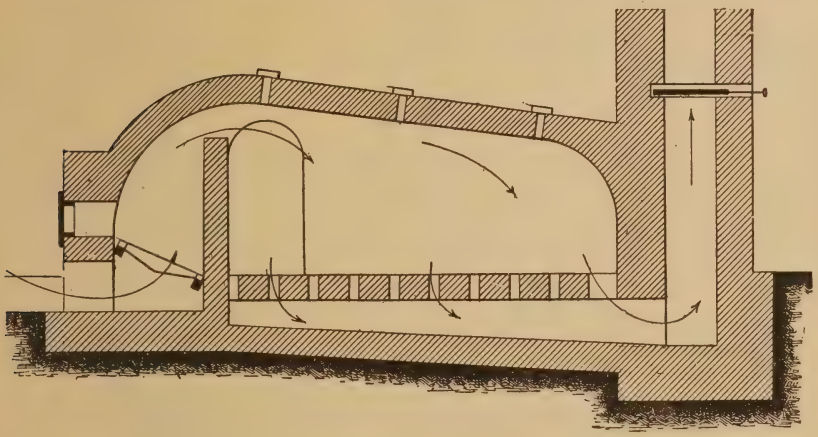


Fig. 151.—Modified Cassel kiln.

required, they travel further through the remainder of the tunnel meeting in their journey a current of air travelling in the opposite direction ; this air is heated by the cooling goods, and gradually attains the maximum temperature of the kiln, so that it is well fitted to ensure the greatest efficiency of combustion. The goods, on leaving the tunnel, are almost cold.

Although tunnel kilns are by no means new they have only lately been worked successfully—chiefly on account of difficulties experienced in controlling them. The modern tunnel kilns are, however, both simple to work and very satisfactory in action.

In the second method, the fireplaces can either be moved about over the fixed goods, or lighted and put out as required. The first arrangement (Barbier, 1885) has long been given up, so that only the other one remains ; it is very extensively used, especially for bricks, many modifications of the arrangement first proposed by

Hoffman and Licht (1858) being now in use. The underlying principle of these *Hoffman kilns* is shown in Fig. 152. A circular burning chamber, A, having twelve doors for filling, B, communicates by means of twelve flues, C (which can be shut by valves or bell dampers, F), with a main flue which is connected with the central chimney, D. A movable damper, which completly shuts off the burning chamber, can be placed near each door ; in the drawing it is shown by door No. 1. The space enclosed between two such consecutive dampers is called a chamber. The kiln shown has twelve chambers,

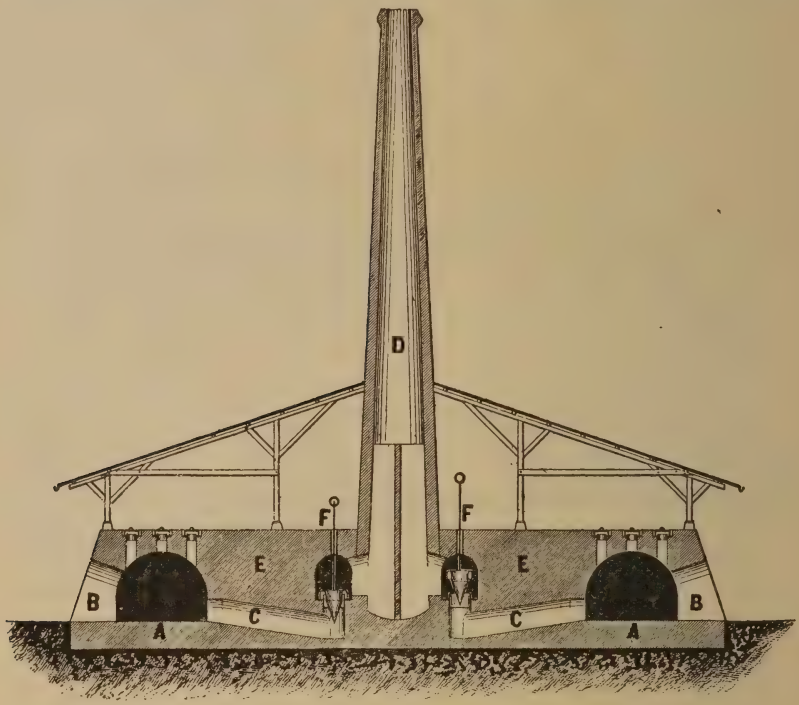


Fig. 152.—Section of circular Hoffman kiln.

each having a door, for filling, at one end, and a flue opening at the other.

Supposing the kiln is working normally, chamber 1 being empty and 2 being filled through door No. 2 ; chambers 3, 4, 5, and 6 contain goods which are cooling ; chambers 7 and 8 are being heated by the fire, and chambers 9, 10, 11, and 12 contain goods which are being gradually heated. The air necessary for combustion enters through door No. 2 (which alone is open, all the others being built up) and passes through the whole length of the burning chambers. It cools the burned goods in its progress, and arrives in the chambers which are being fired, having a temperature nearly equal to that of

the burning fuel. After having been used in combustion and converted into kiln-gases, these traverse the ware to be burned, and, heating it in their progress, finally arrives at the last compartment in which the draught valve, F, is open (all others being closed) and go thence into the chimney.

When the burning of the seventh chamber is finished, the damper between the twelfth and first is taken away, and put between the first, which has just been filled, and the second, which is empty. The bell damper of the first chamber is opened, while that of the second is shut, the door 3 is undone, and door 2 is built up; the different phases of the burning then go on in the same order, but have advanced one chamber. This is continued indefinitely, progressing at the rate of one to two chambers every twenty-four hours, the filling, emptying, and burning being done continuously.

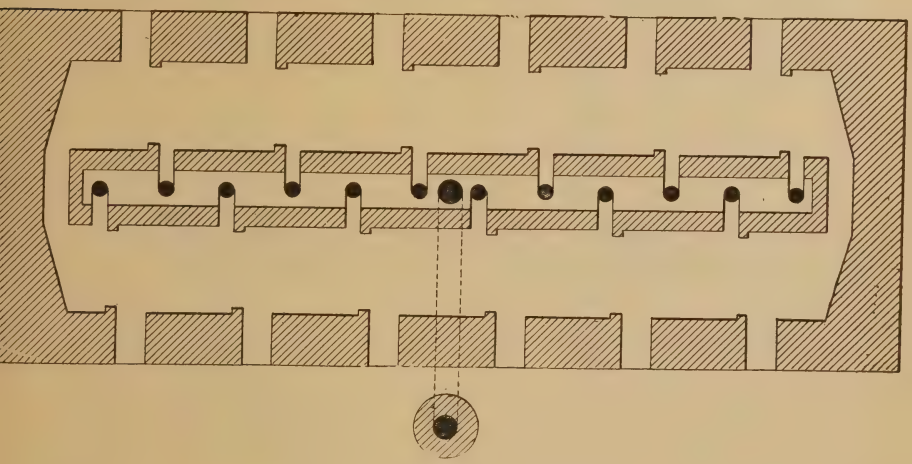


Fig. 153.—Plan of continuous kiln.

The fire is started by building temporary fireplaces in an empty chamber adjacent to the goods to be fired, and by this means the ware is sufficiently heated to ensure the fuel thrown through the top into the nearest heating shafts or fire-pillars (Fig. 128) catching fire, and continuing to burn. These temporary furnaces are kept going until the kiln has begun its normal working, and are then broken down.

In kilns of this type the burning chamber was at first circular, as shown in Fig. 152; later, to secure economy of construction, they were given an oblong form (Hoffman, 1870), then a rectangular form, composed of two parallel galleries united by two flues of communication at the two ends (Bührer, Hamel, Simon). This shape, now almost the only one used, is shown in Fig. 153. The chimney is generally outside, as shown. For small outputs a different form, such as a zigzag kiln, has been used; one of these is shown in

Fig. 154 ; with it and a fan in place of the chimney, Bührer has obtained remarkable results.

The fuel is burnt in fireplaces formed amongst the goods as shown in Fig. 128. Coal is the usual fuel, but logs of wood may be used, or for burning more delicate ware, glazed brick, tiles, etc., gas firing may be employed. One form of gas burner which has given good results consists in introducing the gas through firebrick pipes, called " candles," as shown in Fig. 155 (Society of Schwandorf, 1875). These " candles " are pierced with numerous holes, forming burners, which throw the flames perpendicularly to the current of air. The pipes are connected to a movable iron pipe, which communicates with the gas main in the wall of the kiln. The gas is introduced simultaneously through several rows of candles, and the pipes are moved forward as the fire advances (see also Fig. 244).

There is a second type of continuous kiln in which special furnaces

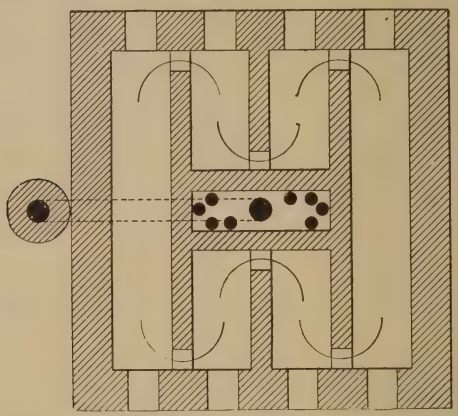


Fig. 154.—Zigzag continuous kiln.

or grates are placed at regular intervals, and the interior of the kiln is divided by walls into a series of chambers from which the name of *chamber kiln* has been given to it ; historically, this is older than the preceding one (Arnold, 1839 ; Jolibois, 1852). Kilns with partitions of this kind can be heated satisfactorily with faggots, straw or other similar fuel ; when coal is used the walls are much closer together. Fig. 156 shows one arrangement, the fuel being fed between two openwork walls, through an opening closed by a sheet of iron. Kilns of this type are also termed *channel kilns.*

In an arrangement which is more suitable when coal is used, each chamber is provided with a grate ; the fuel is fed either through a side door or through openings in the crown, a certain quantity of air being admitted under the grate as well as through vertical channels built in the side walls of the chamber. Fig. 157 shows an arrangement of this kind, used for tile burning (Gilarddoni, Virollet). This kiln is known in Great Britain as the *Belgian kiln,* but the use

of grates and partitions is also an important feature of the various Dean-Hetherington and other well-known continuous kilns; the grates are 9 to 28 in. in width (see also Figs. 157, 245).

Gas-heating is also used in chamber-kilns by using burners in place of the grates or candles.

In continuous kilns, the first phase of the burning, known by the name of *smoking*, ought normally to be done by the general circulation of the gases before they pass out to the chimney, but

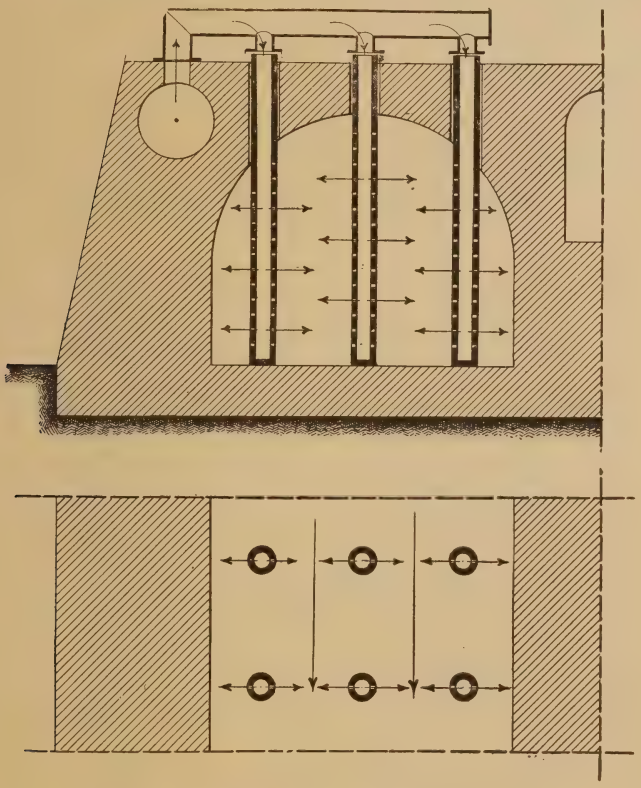


FIG. 155.—Gas-fired continuous kiln, with *candles*.

this method has a serious inconvenience when the goods contain much water, as the gases are so cool that the steam they contain condenses on the ware. This softens the goods, and deposits of soluble salts (*scum*) are often formed on their surface. To prevent this, each compartment should be independently heated to a temperature of about 120° C. before putting it into the general circuit. This heat may be supplied by means of movable stoves, placed against holes in the doorways or wickets or fitting into openings in the roof. For very damp goods it is better to use fixed furnaces,

built along the outside walls of the burning chamber, with flues under the bottom of the kiln ; or, still better, hot air may be drawn from the cooling chambers and passed through *hot air flues* into the chambers to be dried. The great advantage of this method is the purity

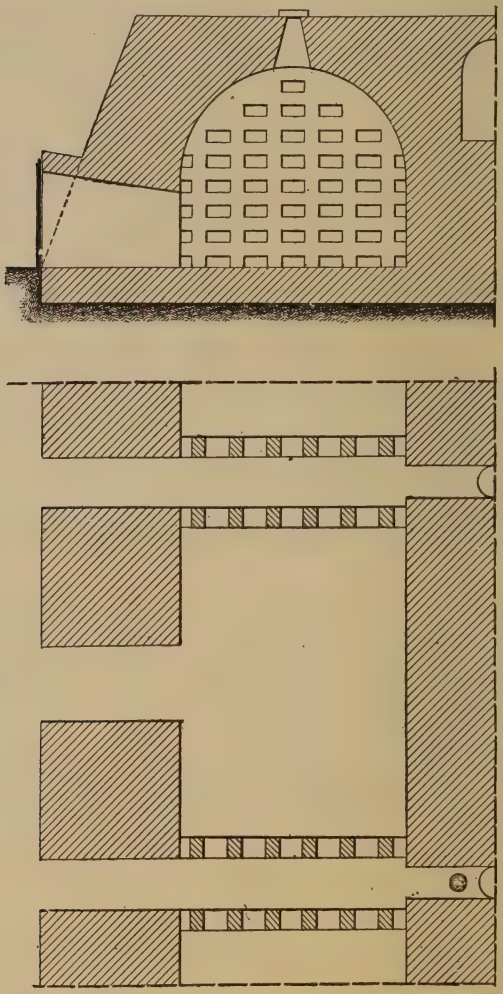


Fig. 156.—Channel kiln designed for using faggots.

of the air, which prevents the formation of scum. In chamber kilns the ordinary furnaces are used for this purpose.

An open continuous kiln of the original Hoffman type, with no partitions or grates and with the fuel distributed among the goods, is the most economical method of heating with coal, but kilns with

partitions are to be recommended for heating with wood (especially when in the form of faggots) and when it is desirable to burn such wares as would be spoiled by contact with the fuel. Gas-heating also gives satisfactory results, especially at temperatures above 1200° C.

Continuous Kilns with Several Chambers.—Burning in open continuous kilns is very difficult when the ware is very delicate, and especially when it needs a very high temperature, because it is not possible to regulate the composition of the atmosphere in the kiln so accurately as is necessary, and the horizontal direction of the gases

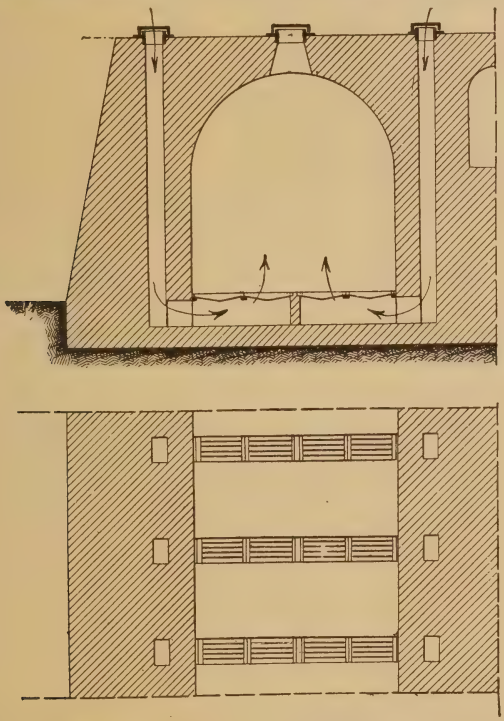


FIG. 157.—Continuous kiln with grates.

is less suitable and does not give as satisfactory a distribution of the temperature as when kilns that have several burning chambers which lead into one another are used.

Of this class of *continuous chamber kiln* there are three principal types :—

(1) *Kilns divided into several chambers by means of partitions, which modify the direction of the gases.*—In the kiln shown in Fig. 158, a horizontal damper, A, permits any chamber to be isolated. The method of heating may be any of those previously mentioned (channels or troughs, grate-furnaces, gas-burners, etc.). The

distribution of the heat is effected in a manner similar to that of single chamber kilns—by means of dampers and by suitable methods of setting the goods.

(2) *Kilns with separate burning chambers, usually of square or rectangular shape, placed side by side and grouped together, so as to form two parallel series, the outside chambers being joined together by two cross flues.*

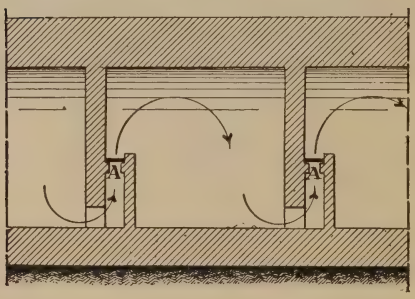


Fig. 158.—Chamber kiln.

Fig. 159 shows a longitudinal section of a Mendheim's continuous chamber kiln heated by coal, by means of four furnaces placed at the four corners of each chamber; the draught is formed by openings spaced regularly in the bottom, which communicate with the next chamber through a series of flues. A supply of air is brought into the chamber under fire, independently of the general circulation of the gases. (A more detailed drawing of this kiln is shown on p. 419.)

Fig. 160 shows a continuous chamber kiln, heated by gas, with

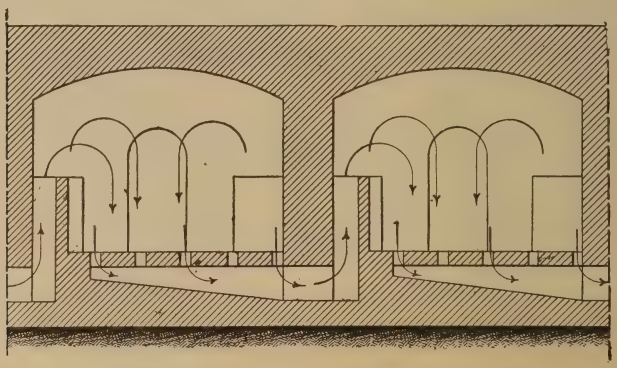


Fig. 159.—Mendheim's continuous chamber kiln.

burners in the floor of the chamber; the air from the preceding chamber, coming through a series of lower flues, rises vertically, descends, and then passes below the partition wall into the next chamber. (A more detailed drawing of this kiln is given on p. 419.)

Fig. 161 shows a continuous chamber kiln also heated by gas, which enters through burners in the crown, whilst the air from the preceding chamber ascends the bag and then descends, passes across the chamber and out by a series of openings in the floor into

the following chamber. It is a mistake, however, to attempt to draw the gas downward, so that this type of kiln is seldom successful.

(3) *Kilns with isolated chambers, each capable of being heated separately as an intermittent kiln, or of being united with the one before and the one after it so as to work continuously.*—Several systems of

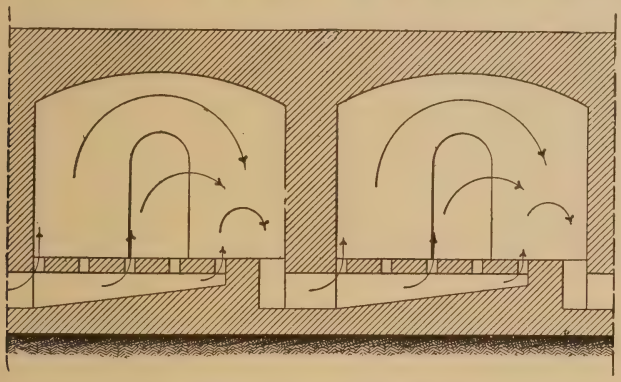


Fig. 160.—Continuous chamber kiln.

this kind have been suggested, but have not been very successful because of their complications and the loss of heat in the flues.

Many improvements in various types of continuous chamber kilns have been made in recent years in Great Britain, the most successful builders being Dean Hetherington & Co., and Wm. Jones

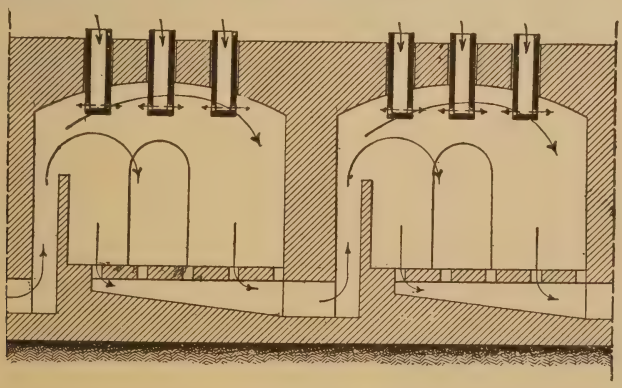


Fig. 161.—Continuous chamber kiln.

& Sons. Numerous firms have also designed special modifications of Hoffman kilns for their own use.

Horizontal intermittent kilns with several fireplaces—often termed *semi-continuous* kilns—are really only portions of continuous kilns, a quarter, a third, or a half of a continuous kiln being constructed. The burning is naturally intermittent, but during the

period of firing the working is almost the same as that of a continuous kiln.

Fig. 162 shows a kiln of this kind, of the same type as the one shown in Fig. 157, except that Fig. 162 is only half a kiln. The fireplaces are at one end of the kiln and the chimney at the other. These kilns are used when the output of a continuous kiln would be too great; their transformation into a continuous kiln is easy. They ought, in most cases, to be chosen in preference to intermittent horizontal kilns with one fireplace (p. 224).

In **muffle kilns** the flames and hot gases do not reach the goods, as the space containing them is heated through outside walls, the heat being transmitted to the ware by conduction and radiation. This arrangement is used for burning wares which would be spoilt by contact with flame, and which cannot be conveniently placed in saggers. The great loss of heat which results from this method of transmission usually prevents muffle kilns from being used for firing

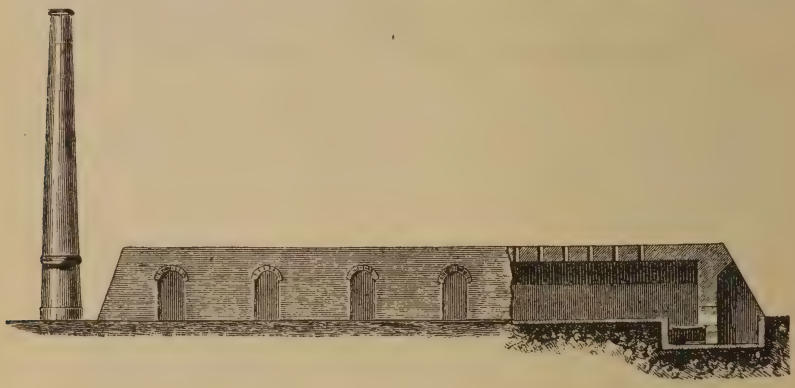


Fig. 162.—Semi-continuous kiln.

wares which need a very high temperature, though they are largely used for sanitary ware. A temperature of 1400° C. in the interior of a large muffle is the highest that can be obtained in practice.

These kilns are generally arranged as shown in Fig. 163, the flames and gases circulating in the space between the outer walls and the muffle. The articles are placed or set through a door in front, which is afterwards closed by a thin partition and a wall, having between them a space to allow of the even heating of this part of the kiln. An air-hole in the upper part allows the exit of the expanded air from the muffle, and a trial hole allows the progress of the burning to be watched. The gases escape by an upper flue and pass into the chimney, which is usually connected with several kilns. The heat is supplied by fireplaces underneath (or at either end), wood, coal, or gas being used. According to the ware to be burned, the size of the internal measurements of a muffle vary from 2 ft. to 30 ft. in length, from 2 ft. to 7 ft. in height, while the

width is only limited by the distance the flames from the fires will travel; it seldom exceeds 12 ft., the practical length that can be given to the fireplace.

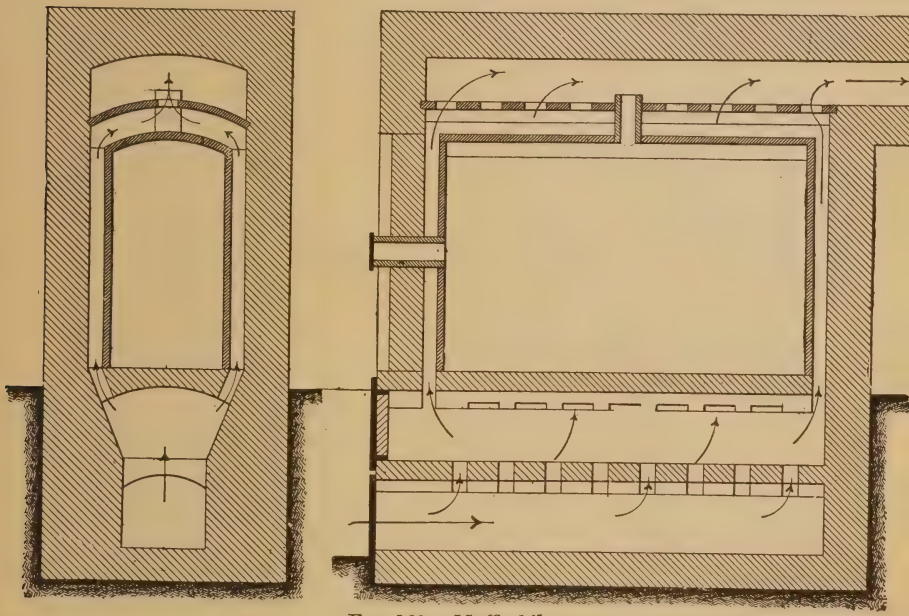


FIG. 163.—Muffle kiln.

A second type of muffle kiln, not so often used, shown in Fig. 164, is heated by vertical pipes, through which the flames pass. These pipes are arranged in parallel rows in groups. In order to reduce the consumption of fuel, several muffles are sometimes built parallel to each other and connected so as to form a continuous kiln in such a manner that the warm gases pass from one chamber to the other, the mode of working being the same as that of a continuous kiln with several burning spaces. Gas-heating is, in this case, preferable to coal.

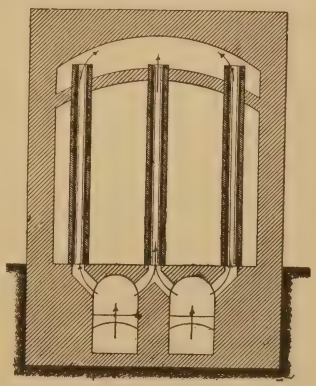


FIG. 164.—Internally heated muffle kiln.

Recuperators and Regenerators.—The best action of a chimney is obtained when the gases leave it at a temperature slightly above 150° C., and if gases are passed out at a higher temperature, the excess of heat in them constitutes a loss, which may be lessened by using regenerators and recuperators.

Care should be taken not to confuse these two terms. In a regenerator the gases and the air to be heated may come into contact with each other, the same passages being used alternately for both. In a recuperator, on the contrary, the gases and air are kept quite separate. Both devices may be used for either intermittent or certain continuous kilns, but not for those of the Hoffman or continuous chamber type, as in these the goods act as a regenerator.

Intermittent regenerators (Siemens) consist of two or more chambers, filled with bricks, placed between the kiln and the chimney. The waste gases from the kiln pass through one of these chambers and yield up part of their heat to the bricks, until the temperature of the latter is so high that it is advisable to shut off the gases and to make them pass through a second regenerator. The heat accumulated in the first can then be used for heating a current of air which is passed through it in an opposite direction to that of the preceding gas. Regenerators of this kind are of very great use in glass-making and metallurgy, but have not been much used in pottery, recuperators being preferred to them.

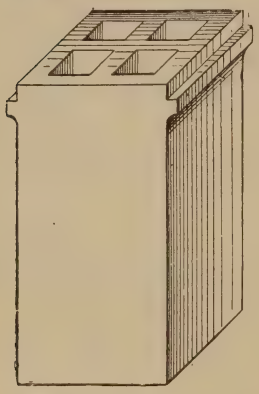


FIG. 165.—Recuperator brick.

Continuous recuperators differ in design, but are always composed of a series of hollow firebricks or pipes placed in such a manner that the gases coming from the fire can pass through them in one direction and the air to be heated in another. Fig. 165 (Gaillard and Hallot) represents a tubular brick of this kind, and Fig. 166 shows the manner in which they are put together to form a continuous recuperator. The warm gases enter by A, and follow the path ABCDE, before passing into the chimney. The cold air enters by F, rises through the holes in the bricks, and passes out, heated, into another chamber, G. Stoppers allow of cleaning the horizontal channels. The difference in the temperature between the exit gases and the hot air is usually from 150° to 200° C. By making the recuperator large enough, the temperature of the waste gases can be reduced to that required for them to pass up the chimney without serious loss of heat.

The air heated in regenerators and recuperators can be used either for drying ware or raw materials, for starting the heating of another kiln, or to supply the secondary air which is necessary for the combustion of gas in gas-fired kilns. They absorb a large quantity of heat before attaining their normal working, so that it usually happens that they are most efficient when the firing is nearly finished, i.e. when they are no longer needed.

Construction of Kilns.—In spite of the many kinds of ovens and kilns used in the ceramic industries, certain general rules for con-

struction should be observed. The first condition is that all kilns must *bear the temperature* to which they are subjected, and also the action of the flames and gases from the fires. It is usually sufficient to make the internal walls or lining of the kiln of bricks having the same power of resistance to the fire as the goods burned in the kiln. This does not apply to muffles or to the brickwork near the fires, as these have to resist the destructive action of the ashes, and should always be made of good firebricks.

It is often difficult to obtain materials that will withstand the action of a large number of successive heatings and coolings ; this question is discussed, with the changes that takes place in special fireclay goods, in Chapter XI.

The second condition is that kilns should resist *the alteration of form* caused by the expansion of the brickwork under the influence of heat. In fireclay ware of good quality, this expansion is $\frac{1}{250}$ to

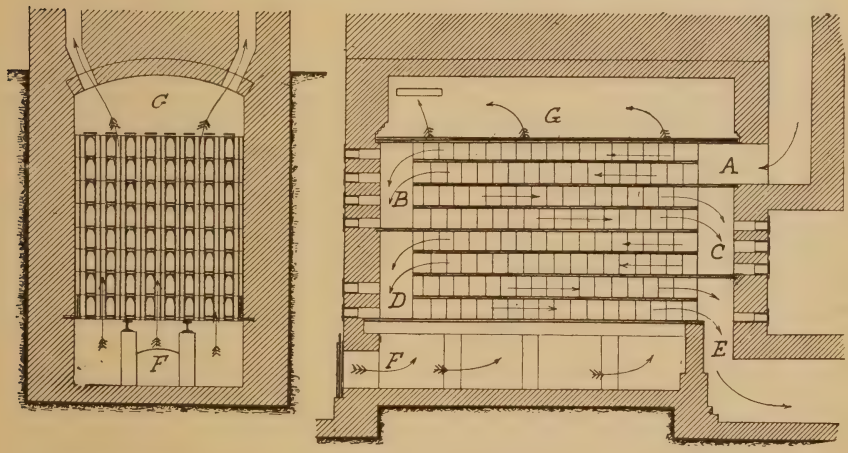


FIG. 166.—Recuperator.

$\frac{1}{200}$ at a temperature of 1000° C. It is greater in ordinary terra-cotta. The inner walls of the kiln, being more strongly heated, increase in volume during the burning, and may force the outer walls, which do not expand, out of shape and crack them. This action has no serious consequence if, when the kiln has cooled, the cracks close up again and if all the brickwork returns to its original shape, but it is serious if the changes are permanent. With each new burning they then increase, speedily necessitating repairs which are always unsatisfactory and end by completely ruining the solidity of the kiln. These inconveniences are remedied either by strengthening the kiln or by separating the inner walls from the outer ones. Round kilns are easily strengthened by means of iron hoops, tightened by wooden wedges or screws. Flat walls and angles are strengthened by upright iron or wooden supports, known as *buckstays ;* the lower end of each is bedded in the ground

and the tops are joined by iron tie-rods and bolts. The space between the inner and outer walls is filled with a layer of cinders or clean sand, or preferably with bricks, as they do not move like a loose material, the outer walls being arranged so that they naturally return to their original position if disturbed. This is specially necessary in continuous kilns which, on account of their large dimensions, would, otherwise, require very costly reinforcement.

It is essential to avoid leakages of air as much as possible, as they interfere with the regular working of kilns. These leaks may be caused by displacement of the brickwork or by its porosity. They are specially prevalent in flues, and it is best to avoid all complicated arrangements and all flues in projecting parts, such as crowns or arches, where they are subject to great expansion, and in all thin walls. Many kilns which, on paper, appear to be very ingenious, give bad results at the end of a short time, because all the flues leak and communicate with one another in undesirable ways.

When the surface of the walls through which air may leak is large, it is advisable to prevent leakage by a layer of cinders or fine sand spread between the masonry or by covering the outer surfaces of the walls with a " daub " or glaze.

The kilns must be protected against damp, for many kilns work badly because, being built on damp or permeable ground, the water from the subsoil, drawn up by capillarity, cools the lower parts and prevents the burning of the ware in them, or forms steam and spoils the draught.

(4) Working of the Kilns.

Whatever may be the nature of the ware to be burned and the type of kiln employed, the burning includes five operations :—

(1) *The setting*, or placing the ware in the kiln.

(2) *Smoking*, which consists in heating the ware to a temperature of about 120° C.

(3) *The burning proper*, which is most usually subdivided into slow firing, full fire, and annealing.

(4) *Cooling* the ware in the kiln.

(5) *Emptying* or drawing the kiln.

Three methods of setting are used ; the choice depends on the nature of the ware :—

(*a*) For strong, porous ware, which does not soften in burning, the goods are piled on one another in such a manner as to fill the kiln completely, with the exception of the spaces necessary for the circulation of the flames and gases and to distribute the heat uniformly. Fig. 128 shows one method of setting plain bricks in a continuous kiln, and other examples may be found in the chapters relating to other industries. This method of setting is applicable to most terra-cotta and to some kinds of stoneware. The more fragile articles, which usually need less heat, are placed in the

upper parts of the kiln which are further from the fires. Open setting is only applicable to wares which do not suffer from contact with the flames, unless the burning is done in muffle kilns, which is often less economical than saggars. Glazed goods can seldom be burned in open kilns unless the glaze only partially covers the goods, and then only the unglazed surfaces may be in contact. Glazed articles are usually burned in muffles, "boxes," or saggars.

Setting with quarries or slabs is employed for fragile and vitrifiable wares, or large pieces of glazed sanitary ware, which are burned either in ordinary kilns or in muffles, according as the ware can or cannot be exposed to the flames. Fig. 167 shows an example of this kind of setting in which A represents the walls of the kiln; B, small pillars of fireclay often made of bricks on thick slabs, and C, fireproof slabs. The latter are perforated in such a manner as to allow the gases to circulate. The goods rest on these slabs on an unglazed surface. Setting in saggars is used for unglazed, non-

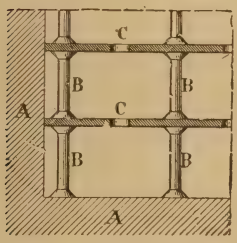


Fig. 167.—Setting in "cupboards."

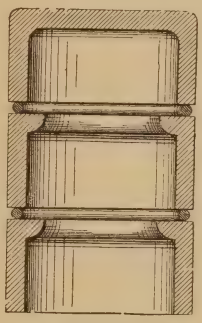


Fig. 168.—Saggars.

vitrifiable ware, which suffers from the action of the flames, but which need not be burned in the muffle, for glazed wares, and for those which are liable to get out of shape if heated under pressure.

Saggars are fireclay boxes of various shapes and dimensions; they should be glazed inside when glazed goods are to be burned in them. They often have the form shown in Fig. 168, and are placed one on the other, in piles, with rolls or "wads" of fireclay paste between them. The wads serve at the same time to join the saggars together and to make them firm. The diameter of the saggars varies according to the size of the articles to be burned in them; saggars are usually oval, but are sometimes square or rectangular.

Putting the ware in place in the saggars or into the kiln is termed *placing* or *setting*. If the ware is unglazed and non-vitrifiable, it is placed in the inside of the saggar, piled up; a fireclay slab from time to time is put inside the saggar (Fig. 168) to divide the pile into a series of cases, placed over one another so that the lower goods do not bear the whole weight of the charge. This arrangement is

indispensable when the goods are of such a shape that they cannot be placed on one another in a high pile.

When glazed articles are to be fired, they are stood upright on an unglazed part, but they cannot be piled directly on one another, because the fusion of the glaze would make them stick together. In this case, each saggar is shaped like the top one in Fig. 168, but inverted. Under certain conditions, it is sufficient to place small supports in holes in the sides of the saggars so that the articles can rest on these supports. The sharp top of these supports prevents the glaze from adhering too much, and leaves only a slight mark when the ware is fired. In the same way, very light goods may be piled on one another by separating them with small fireclay pieces (*stilts*) which only come in contact with the ware at points, thus producing only a little prick on the glaze. In Chapter XII are shown examples of the latter methods of placing, which are specially used for fine pottery.

When the bodies soften in the kiln, the difficulties of setting are much greater, because it is necessary to prevent the ware being misshapen. Such articles can no longer rest on spikes or points; each one must be set separately in a case formed either by saggars or by other fireclay pieces of suitable shape. This method of setting is peculiar to porcelain; it is described in more detail in Chapter XIV.

When all the precautions needed by the nature of the ware have been taken, and the articles have been placed so that the hot gases may circulate freely through them, it is necessary—to economize fuel—to allow a sufficiently large quantity of air to enter the kiln.

Smoking,[1] sometimes yet improperly called *stoving*, is intended to evaporate the water contained in the body, the glaze, the pieces used in setting, and in the walls of the kiln. It is finished when the interior of the kiln is at a uniform temperature of about 120° and when the gases passing to the chimney no longer contain steam other than that derived from fuel.

Smoking is very simple when the ware is thin and comparatively dry, but is much more difficult when the goods are thick and damp, as there must be evaporation without bubbling, so as to avoid steam under pressure in the ware, which would make it split. At the same time, the steam given off from the goods near the fireplaces must be prevented from condensing on the cool ware farther off, or it will soon soften the latter and cause spots. To avoid this, the steam formed must be removed as quickly as possible—which is not always easy with kilns with down or horizontal draught, because the steam, being lighter than air, tends to accumulate in the top of the kiln. It is best to make as much use as possible of an up-draught for this operation. The fuel used should be dry, and should burn

[1] The term *smoking* or *water-smoking* is supposed to be derived from the evolution of clouds of steam (white smoke) evolved at this stage when the ware is damp.

with a slow, regular action, and not much flame. Hard, dry wood and coke give the best results. The proportion of air entering the kiln should be large and gradually reduced as the temperature increases, but the object of this heating should always be to obtain moderately warm air, and not to raise the temperature of the kiln unduly.

To determine the extent of the smoking, self-registering mercury thermometers graduated to 200° C. or 400° F. are lowered through the trial holes into the different parts of the kiln, and are drawn out again at the end of some minutes. The temperature shows the progress of the heating, and the smoking should not be considered complete until every part of the kiln or chamber has reached a temperature of at least 120° C. or 250° F. Instead of a thermometer some firemen use a long iron rod or poker—preferably of polished metal—which they insert into various parts of the kiln or chamber. The rod must be cold, so that if any moisture is present it will condense on the cold metal. After withdrawal, the rod is carefully examined, and if there are any drops of moisture on it, the smoking must be continued. Only when the rod is quite dry when drawn out of the trial holes furthest from the fireplaces can the smoking be considered to be finished.

Firing proper is the term applied to that part of the firing which extends from the end of the smoking to the end of the heating. It may be divided into three stages, which are not wholly distinct:—

(i) *Slow firing*, in which the temperature rises to about 700° C. This stage is the one in which the true clay (alumino-silicic acid) and analogous compounds are decomposed; the temperature should rise slowly, or the large quantity of water evolved (13 per cent in some clays) will crack the ware.

(ii) *Full fire*, beginning at about 500° C., and continuing until the whole of the ware has reached the maximum temperature required. This part of the firing is characterized by a quicker and sharper heating.

(iii) *Annealing*, a state of variable duration, according to the thickness of the ware and the method of setting. During this period, the necessary temperature having been reached, it should be maintained until the ware has been evenly heated throughout, the heating being continued until the ware has the requisite properties. The chief purpose of this stage of the firing is to ensure the requisite amount of vitrification without distortion. It is based on the fact that a prolonged heating at a given temperature will ensure the same amount of vitrification as a shorter heating at a higher temperature, but as the vitrification proceeds more slowly there is far less risk of the ware losing its shape.

The mode of firing depends entirely upon the nature of the ware, the type of the kiln used, the effect desired, the quality of the fuel, and the composition of the atmosphere in the kiln.

The Atmosphere in the Kilns.—The influence of the composition of the atmosphere in the kilns has already been mentioned (p. 194).

This atmosphere is *oxidizing* when the fuel burns in an excess of air, so that the kiln atmosphere contains some free oxygen. The normal composition of air is 21 per cent of oxygen and 79 per cent of nitrogen by volume, or 23 per cent of oxygen and 77 per cent of nitrogen by weight. Consequently, if the gases passing out of the kiln contain 10·5 per cent of oxygen by volume or 11·0 per cent by weight, then the combustion has been carried on with double the amount of air that is strictly necessary. In most cases a large excess of air is employed so as to ensure complete oxidation.

The atmosphere is *neutral* when it contains neither oxygen nor combustible gases, and in this case would contain about 21 volumes of carbon dioxide to every 79 of nitrogen, if pure carbon were used as fuel, but as there are always hydrogen or hydrocarbons, the combustion of which produces steam, and traces of oxygen and carbon monoxide are always present, the proportion of carbon dioxide seldom rises above 18 or 19 per cent.

The atmosphere is *reducing* when there is an excess of combustible gases such as carbon monoxide, hydrogen, or hydrocarbons; with no free oxygen and the proportion of carbonic acid gas is below the limit just mentioned.

The earlier stages of firing are usually effected under oxidizing conditions; the reduction (when required) being confined to the later stages. This is necessary in order to burn out any combustible matter in the body, to ensure a better control of the reduction, and to lessen the amount of fuel used, as firing under reducing conditions is very wasteful in fuel.

The composition of the atmosphere in the kilns depends on the arrangement of the fire, the nature and method of feeding the fuel, and on the draught. An oxidizing atmosphere can easily be obtained in any kind of fireplace by using a small amount of fuel and a strong draught, thus introducing plenty of air. On the contrary, a decidedly reducing atmosphere needs a thick layer of fuel and a small draught, i.e. a small quantity of air; only furnace fireplaces and gas firing can produce it under normal conditions.

By referring to the fireplaces shown in Figs. 125, 126, 128, 129, and 130, it can easily be seen that after each charge of fuel there is a considerable evolution of combustible gases which are only partially burnt, as may be seen by the black or brown colour of the smoke. After several moments the combustion becomes complete, and air is in excess, until a new charge of fuel causes the same disturbance. A very methodical heating, with stokings at very short intervals, as in kilns with continuous firing, decreases these irregularities without wholly avoiding them. In order that fireplaces of this kind may work well, they should be worked oxidizing and only allowed to become neutral or even reducing for a very few moments after each charging. This is effected by light and frequent firings; heavy charges of fuel have the opposite effect. The addition of fuel to a kiln is commonly termed "baiting."

It is different with fire-boxes (Figs. 127, 133, 134, 135), the feeding

of which ought, when well done, to cause only slight changes in the kiln atmosphere. This is more affected by the periodical cleaning of the grates, which, by reducing the resistance to the circulation of the gases, causes a variation in the weight of air entering the kiln. It is usually possible to avoid cleaning the grates at unsuitable periods of the burning. In fire-boxes it is easier to regulate the thickness of the layer of fuel, and, consequently, the composition of the atmosphere of the kiln.

The thickness of the layer of fuel suitable for the different stages of firing depends on the nature of the fuel, its size, and the proportion of ashes and clinker in it. The larger the pieces and the purer the fuel, the thicker should be the layer. A medium coal with a thickness of 12 to 16 in. gives a neutral atmosphere, a lesser thickness produces an oxidizing atmosphere, and a greater one a reducing atmosphere.

Gas-heating in skilled hands ensures a regular composition in the atmosphere of the kiln, and one which is easily regulated, but in unskilled hands very irregular results may be obtained.

Even with gas, it is impossible to obtain during the whole of the burning, or even during a long space of time, an absolutely regular atmosphere, and all that is possible is to reduce the errors to the narrowest limits.

If the temperature of the burning is low or medium, it is easy enough to manage the heating with a decidedly oxidizing or reducing working, but if a high temperature is required, the introduction of a large excess of air, or an incomplete combustion, lowers the temperature of the gases passing out of the fires so that the kiln atmosphere becomes almost neutral and does not contain more oxygen or combustible gases than are strictly necessary to act upon the iron oxides. Hence it is very difficult to secure a decidedly oxidizing atmosphere at temperatures above 1250° C.

Another consideration which necessitates a neutral or nearly neutral atmosphere is that the flames must be of a sufficient height or length to reach right across the kiln. When a large excess of air is used, the flames are much shorter than if the proportion of air were only that strictly necessary. A final point of importance when using saggars is the various speeds with which the different gases can pass through fireclay. If the speed of diffusion of air is 1, oxygen has a speed of only 0·949, combustible gases and hydrogen a speed of 3·800, carbon monoxide 1·015, saturated hydrocarbons 1·344, and unsaturated hydrocarbons 1·019. Hence the atmosphere inside saggars tends to be much more reducing than that in the kiln proper.

Analysis of the Kiln Gases.—The determination of the composition of the atmosphere in a kiln may be made by (i) direct observation of the flames and gases passing out of the chimney; (ii) chemical analysis; and (iii) measuring their density.

Although the method of direct observation is both primitive and uncertain, it is, except in certain special cases, the only one commonly used. It is based on the following signs: when the flames

are short, brilliant, with clearly marked edges, and when their extremity is clearly recognized, the atmosphere is oxidizing. If, on the contrary, the flames are long, cloudy, with uncertain edges, their extremity ill-defined and smoky, the atmosphere is reducing. If the gases passing out of the chimney have a bluish or black colour, but only at the time of stoking, it is a sign that the combustion is moderately complete. If, on the contrary, the colour is constantly yellow or red, with a black colouring after the stoking, the combustion is incomplete. These observations suffice for most practical purposes ; but not when an atmosphere of specified composition is required at certain parts of the burning ; chemical analysis must

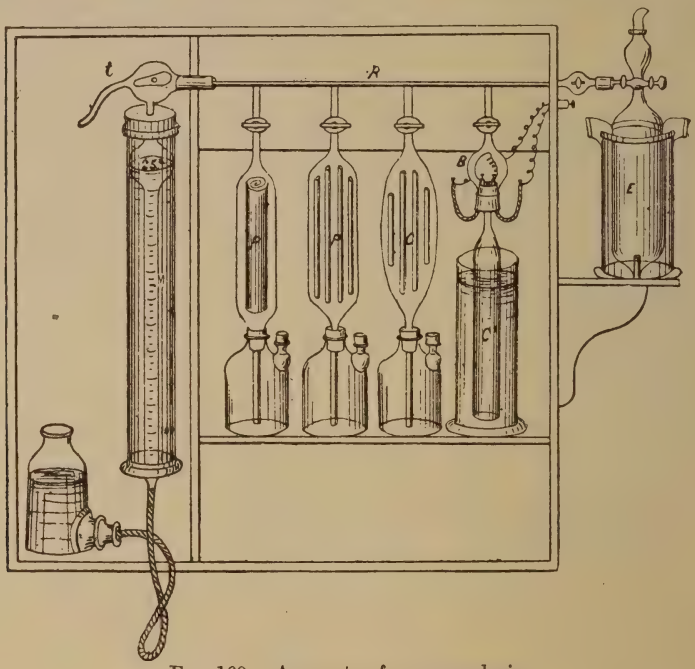


Fig. 169.—Apparatus for gas analysis.

then be employed. For this purpose, the Orsat apparatus is used, or a modification of it such as that shown in Fig. 169. A graduated glass tube *m*, or measurer, surrounded by water to keep the temperature constant, is divided into 100 c.c. ; in the lower part—which is of lesser diameter—the graduation is made in tenths of a cubic centimetre. An india-rubber tube connects the apparatus to a bottle containing water. The top of the tube is connected to a capillary tube, R, fitted with a tube *t*, at one end for the introduction of the gas, at the other with a gas-holder, E, and intermediately with four receptacles : P′, containing potash ; P, pyrogallate ; C, cupric chloride ; and B, a burner surmounting the bell C′. All the

connexions with the tube R being closed, the measure *m* is filled with water by raising the bottle; then after having placed the tube, *t*, in connexion with the gas to be analysed, the bottle is lowered again, so as to fill the measure exactly with 100 c.c. of gas. After having closed the tube *t*, the communication with the receptacle P′ is opened, and the gas is forced into it by raising the bottle. In a few moments the gas is passed back into the measure by again lowering the flask, and the new volume of the gas is read on the graduated scale, the difference showing the proportion of carbon dioxide. The analysis is continued in the same way by making the gas pass into the second vessel P, which absorbs the oxygen; into C, which takes out the carbon monoxide; into E, in which are added some drops of bromine, to retain the unsaturated hydrocarbons; and, lastly, into B, where, by the addition of a definite quantity of oxygen, the hydrogen and saturated hydrocarbons are fired by an electric current and converted into water and carbon dioxide. The volume of carbon dioxide produced is afterwards absorbed in the receptacle P, and indicates the proportion of hydrocarbons, and the reduction in volume shows the proportion of hydrogen. The remaining gas is nitrogen.

This method of analysis, when applied to the combustible gases produced in gas generators, shows accurately the composition of the gas manufactured. For kiln gases it is usually simplified by merely determining the proportion of carbon-dioxide, oxygen, and carbon monoxide; this shortened analysis can be done in a few minutes; and the variations in the composition shown by the gases during the progress of a burning make a lengthy analysis delusive. Apparatus for the automatic analysis of kiln gases is available.

The determination of the proportion of carbon dioxide in kiln gases from their density is based on the fact that the density of carbon dioxide is considerably greater than that of air (1·529). Several forms of apparatus have been invented on this principle, which show the proportion of carbon dioxide on a dial. They are so extremely sensitive that the least dust or the slightest impurity in the gases makes the result erroneous, and they are only applicable to kilns with a constantly oxidizing atmosphere, because all combustible gases being lighter than air it is impossible to draw any conclusion from the density of the gaseous mixture in which they are found, even in a small proportion. Hence, this method is of very limited application in the ceramic industries.

Measuring the Draught.—The draught is regulated according to the desired intensity of the fire, the length of the flames, and the composition of the atmosphere. Direct observation is usually sufficient to enable practical men to regulate the position of the dampers, but it is advisable to measure the draught, as the results thus obtained make it easier to regulate later burnings.

The gauges used for measuring draught are very simple; all give good results, but the apparatus shown in Fig. 170 is the one usually preferred. It is composed of two flasks, each with an area

ten times as large as the U-tube joining them. One flask is connected by an india-rubber tube and iron pipe to the part of the kiln where the measurement of the draught is desired, and the other is open to the atmosphere. They are filled with two liquids, chosen in such a way that they do not act on one another, and having densities sufficiently different for the liquids not to mix together, for example, water and phenol coloured black with an aniline dye. They are so arranged that the surface of the separation of the liquids is opposite the zero of the scale, the position of which can be altered to suit. The depression in one of the flasks causes a difference of level of the liquid in the other, which is multiplied by 10 in the U-tube, so that the actual draught is one-tenth of that measured on the graduated scale.

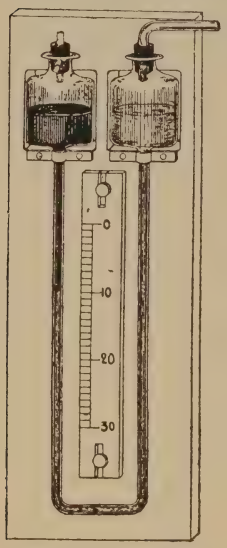


Fig. 170.—Draught gauge.

Recording draught gauges are invaluable; not only do they show the variations in the draught, but a specimen chart enables the burner to regulate the draught so as to correspond to that shown on the specimen chart, and thus to avoid many mistakes which would otherwise be made. Incidentally, a recording draught gauge shows far better than anything else the great advantage of a fan over a chimney in the production of a regular and easily controlled draught.

Measuring the Temperature.—The temperature of the kilns may be estimated by the eye, according to the colour of the ware or the walls of the kiln. The figures in the following table, due to Poillet, are generally adopted :—[1]

	Degrees C.
Red—just visible	525
Red, dark	700
Cherry red—just visible	800
Red—clearly visible	900
Red, bright	1000
Orange, dark	1100
Orange, bright	1200
White, bright	1300
White, dull	1400
White, shining	1500

In order to be accurate, the observer should be in the dark, so that his eye may not be influenced by the varying brightness of the sun's light. The tint of the inside of the kiln can then be easily

[1] These results are too high; the orange tints frequently appear at about 1000° C., and the white ones at about 1200° C. It is wiser, therefore, to record the colour noticed and not the temperature, according to Poillet's table.

recognized, if the atmosphere is not too disturbed, but is more difficult with a reducing atmosphere. The brightness of the flames, which are white when hydrocarbons are burning, and blue when produced by carbon dioxide or hydrogen, is also disturbing to an inexperienced eye.

In kilns set open, the advance of the burning can also be estimated by the shrinkage, or by the extent to which the height of the goods in the kiln has been lowered. This does not measure the temperature, but only shows whether a certain degree of burning (heat effect) has been reached. The shrinkage is measured with an iron rod, on which is marked the distance between a fixed point in the kiln and the upper part of the ware. This method, as described, can only be used for bricks, roofing tiles, etc., set openly in the kiln, and not for articles which are fired in saggars. The shrinkage of such articles is measured by putting "trials" in broken saggars in such positions that the trials can be withdrawn as desired and their shrinkage measured with calipers.

For all pottery needing more exact firing, *pyroscopes* or *pyrometers* are used to determine whether the temperature necessary for the burning has been reached.

A *pyroscope* is a device which indicates the temperature, or more strictly, the effect of heat, by the change which takes place in the material of which the pyroscope is made. In one form, a test-piece or *trial* coated with a suitable glaze is put into the kiln and drawn out through special sight holes during the burning to see whether the glaze has melted. When the last test taken out has proved that the burning has reached the desired state, it is still necessary to continue the firing for a certain time, regulated by experience, so that the goods (which are usually thicker or more protected than the test pieces) may receive the same amount of heating throughout. Various coloured glazes, coloured bodies, and even plain colours (such as gold colour, p. 276) are sometimes used as pyroscopes, the temperature or heat effect being judged by the change in the colour of the test piece or *trial*.

Another form of pyroscope consists of certain metals which melt at specified temperatures. The following table shows the metals which can be used and the temperatures corresponding with their change of state :—

Fusion Points.

	Degrees C.
Tin	233
Lead	325
Zinc	433
Aluminium	625
Zinc (volatilization)	930
Silver	954
Gold	1045
Copper	1054
White pig-iron	1130
Grey pig-iron	1220
Nickel	1410
Palladium	1500
Platinum	1775

The layer of oxide formed usually falsifies the results, and it is preferable to replace them by siliceous mixtures such as those devised by Seger, who made a series of pieces (known as *Seger cones*) of the form of the largest tetrahedron shown in Fig. 171. This illustration shows the manner in which, under the influence of heat, the cones bend over before melting. To measure the temperature of a kiln, a series of cones must be placed in the kiln opposite a sight-hole ; as the temperature corresponding to the most fusible cone is reached it will change its shape, as shown in Fig. 171, and will then melt. As the temperature rises, other cones will bend in turn. The maximum temperature attained is that at which one cone has bent until its apex is nearly level with the base. When the maximum temperature desired is known, it is sufficient to use the three nearest cones to regulate subsequent burnings, one cone being bent at 20 degrees below the required temperature acts as a *warner*, the second

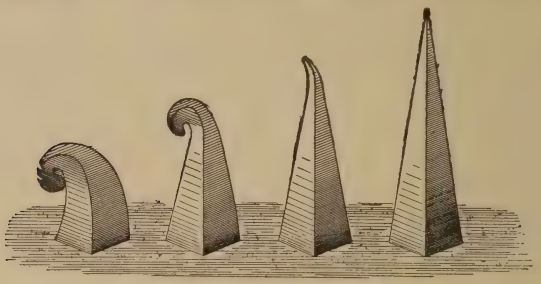


Fig. 171.—Seger cones.

cone indicates the required temperature, and the third cone will indicate whether that temperature has been exceeded.

The following are the numbers of Seger cones generally used in pottery :—

	Seger Cone.
Muffle firing for decoration	022 to 010
Burning fusible bodies	015*a* „ 01*a*
Burning slightly fusible bodies	1*a* „ 10
Red bricks and tiles	015*a* „ 01*a*
Stoneware burning	5*a* „ 10
Burning body for fine earthenware	3*a* „ 10
Burning glaze for fine earthenware	010 „ 01
China ware (biscuit)	9 „ 10
Burning fireclay ware and porcelain	5*a* „ 20

Cones 26 to 42 are only used in experiments on fusibility and refractoriness. Cones can be prepared corresponding to the compositions in a table published by Seger, but as they are not easy to make and can be bought cheaply, it is far better to purchase them ready for use.

Holdcroft's thermoscopes are small bars which are supported at their ends in a horizontal position in the kiln. When the critical temperature of a bar is reached it sags in the middle.

The following temperatures are indicated ;—

HOLDCROFT'S THERMOSCOPE BARS.

(*Approximate Bending Temperatures.*)

Bar No.	Temperature.		Bar No.	Temperature.	
	° C.	° F.		° C.	° F.
1	600	1112	22	1080	1976
2	650	1202	23	1100	2012
3	670	1238	24	1120	2048
4	700	1292	25	1140	2084
5	730	1346	26	1200	2192
6	760	1400	26*a*	1230	2246
7	790	1454	27	1250	2282
7*a*	810	1490	27*a*	1270	2318
8	840	1544	28	1280	2336
9	860	1580	29	1300	2372
10	875	1606	30	1325	2415
11	890	1634	31	1350	2462
12	905	1660	32	1380	2516
13	920	1688	33	1430	2606
14	935	1715	34	1460	2660
15	950	1742	35	1475	2688
16	960	1760	36	1490	2714
17	970	1778	37	1505	2740
18	985	1806	38	1520	2768
19	1000	1832	39	1535	2796
20	1040	1904	40	1550	2823
21	1060	1940	—	—	—

Other pyroscopes of a similar character are also used, but as the same principle (change of shape by partial fusion at a given temperature) is involved, they need not be described.

Pyrometers are much less frequently used in pottery than are cones and trials, but their use has greatly increased during the past few years.

Wedgwood's pyrometer, which is really a shrinkage gauge, is now seldom used.

The *water pyrometer* by de Saintignon consists of an iron tube put in the kiln, through which a current of water, having sufficient velocity to prevent evaporation, flows. The difference in temperature between the water entering and coming out of the kiln, as measured by thermometers, is proportional to the temperature of the kiln. This apparatus is no longer used.

In the *actinometric pyrometer* by Latarche a mercurial thermometer outside the kiln receives the radiation of part of the interior, so that the temperature shown by the thermometer is proportional to that of the kiln.

Siemen's *electric pyrometer* is based upon the difference in resistance offered to an electric current by a platinum wire, this varying according to its temperature. This delicate apparatus, which is

easily disarranged, is chiefly suitable for scientific researches on firing.

In the *thermo-electric pyrometer* by Le Chatelier an electric current, varying in strength, which is produced by heating a couple formed of a platinum wire and a wire of an alloy of platinum with about 10 per cent of iridium or rhodium, is measured by an aperiodic galvanometer, the deviations of which are noted by means of a Poggendorf reflector. The couple must be fixed in that part of the kiln of which it is desired to measure the temperature, care being taken that there is no movement of air around the wires ; the galvanometer must be put in an isolated position. This type of pyrometer gives most accurate results. Those made by the Cambridge and Paul Instrument Co., Ltd., and by The Foster Instrument Co., Ltd., are the most popular.

When the temperature of the kiln exceeds 1400° C., a radiation

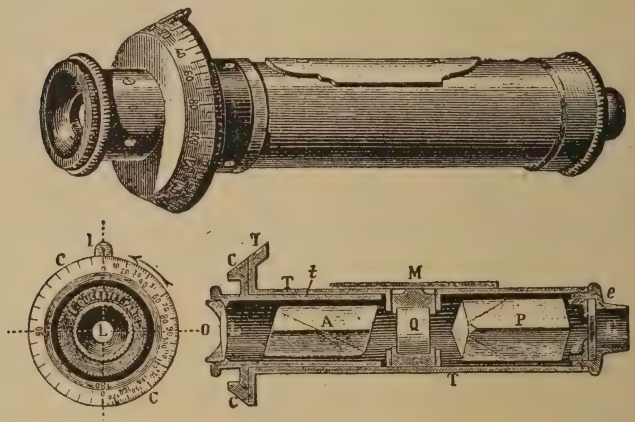


Fig. 172.—Optical pyroscope.

or optical pyrometer is preferable ; this type is also made by the firms just mentioned.

The Féry pyrometer is similar to that shown in Fig. 173, but instead of it being entirely optical, the heat rays are received on a thermo-couple and the current produced is measured by a galvanometer. This instrument is quite satisfactory for most pottery purposes, but it is somewhat delicate.

The *pyrometric telescope* by Mesure and Nouel is a portable apparatus, shown in Fig. 172, with which an object placed in the kiln can be viewed. It is based on the phenomena of rotatory polarization of light. The luminous ray entering by A crosses two Nicol prisms, P and A, which are separated by a quartz disc, Q, before arriving at the observer's eye placed against the object glass, O. The colour seen varies according to the intensity of the luminous source ; by turning the eye-piece in the direction of the graduation

of the circle, C, a certain position of the prisms is found at which the colour passes rapidly from green to red, with an intermediate position at which there is a dirty citron shade. The measuring of the temperature is determined by the number of degrees that the eye-piece has been turned, starting with the zero of the apparatus until the moment when this shade disappears. This telescope may be put into the hands of a fireman and is of great use in regulating the upward rise of the temperature, the trials, on the other hand, showing when the maximum heat effect has been reached. Similar pyroscopes are made in this country.

The *optical pyrometer* by Le Chatelier is based on the comparison of the light emitted by a definite part of the kiln with the flame of a standard lamp; Fig. 173 shows the arrangement. The lamp, L, gives out luminous rays which are reflected by the mirror, M, and perceived by the eye, placed at the eye-piece, O. On the other hand, the rays coming from the kiln through the opening, A, are also perceived at the eye-piece, the two images being side by side and thus easily compared. Their intensity is equalized by inserting darkened glasses, B, and by reducing the opening of the diaphragm, C. To make observation easier, a red glass, D, is placed before the object in such a manner as to allow only monochromatic rays to pass. The apparatus is calibrated by viewing at a small palladium globe, soldered on to a thermo-electric couple, the temperature of the globe being known. In a modified form of this pyrometer an electric lamp is used.

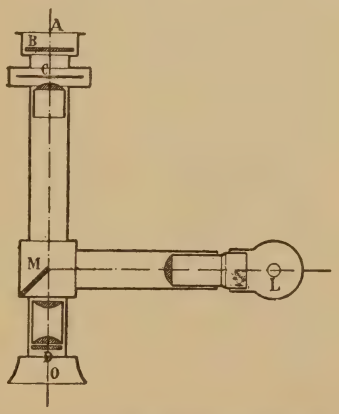


FIG. 173.—Le Chatelier pyroscope.

Optical pyrometers do not readily get out of order, and give results which are comparable; but the observer must be careful that the rays emitted by the object in the kiln do not encounter gases or flames, which would falsify the results.

Cooling and Emptying the Kiln.—When the maximum temperature has been reached and it has been maintained long enough to accomplish the annealing, the ware must be allowed to cool until the kiln can be emptied. If the cooling may be done in an oxidizing atmosphere it may sometimes be hastened by allowing a current of air to pass into the kiln. This air may be used for heating other ware, or it may escape by the chimney or through openings in the top of the kiln.

If, on the contrary, the atmosphere must be kept reducing, all circulation is stopped and the cooling is only accomplished by radiation from the walls of the kiln, the kiln being sealed until the composition of the atmosphere will no longer affect the colouring, i.e.

until the glazes have solidified or the bodies have a temperature below dark red. After this, the cooling may sometimes be hastened, as in the preceding case. The same precautions must be taken as in heating, so as to avoid too sudden or uneven cooling which would make the ware split. When the goods are nearly cold it is specially necessary to avoid undue haste in taking them out of the kiln.

Emptying the kiln is a very simple operation, although often very difficult because of the heat, and does not need any special description.

The thermic yield of a kiln is determined from the relation of the heat really used to burn the ware and that produced by the combustion of the fuel. If c be the number of calories really used, and C the number of calories produced in the kilns, the relation $\frac{c}{C}$ represents the yield of the kiln, and $\frac{C - c}{C}$ the proportion of heat lost. Although this definition is simple, the calculations and observations which have to be made to find the value of c and C are very difficult. It is best to try to find the value of c first, and then to take account of all the loss of heat. The sum of all the amounts thus obtained gives the number of calories C, this being also determined independently by multiplying the weight of fuel used by its calorific power.

The number of calories theoretically necessary to burn a definite weight of pottery may be reckoned as follows: The heat necessary for raising this weight of pottery to the maximum temperature T is found by multiplying the weight of the ware and saggars (in grammes) by the specific heat (0·2) and then by the rise in temperature (in centigrade degrees); to this must be added the heat absorbed by the evaporation of moisture, by the decomposition of the clay, the inversion of the silica, and the breaking up of the carbonates. On the other hand, the formation of some silicates is accompanied by an evolution of heat. As the heat evolved or absorbed by the formation or decomposition of the silicates has not yet been determined, it is usually assumed that these two phenomena counteract one another, though this need not be the case. Assuming it is correct, however, the heat used to raise 1 kilogramme of burned ware from 0° to T° is equal to 0·2T, assuming the specific heat of pottery to be 0·2. As T varies from 800° C. to 1375° C., the value of 0·2T is 160 to 275 Calories.

If the quantity of combined water contained in the *dry* body is a per cent, the heat necessary to evaporate it at 500° C. is

$$\frac{a}{100 - a}[606{\cdot}5 + (0{\cdot}305 \times 500)].$$

a, at its maximum, is equal to 13·9, which corresponds to 122·5 Calories.

The free water or moisture at b per cent gives about

$$\frac{b}{100 - b} [606{\cdot}5 + (0{\cdot}305 \times 100)] \text{ Calories.}$$

If b varies from 4 to 6 per cent this gives 26·5 to 40·7 Calories.

Thus 1 kilogramme of burned ware needs, theoretically, a maximum of 445 calories for burning it, and may only need 245 calories for fusible bodies. If carbonate of lime is present, it would be necessary to add to these numbers $\frac{21{\cdot}7 \times n}{100}$ Calories, n being the proportion of carbonate in the body (Berthelot); but this amount, when small, may be neglected, and the total heat essential for burning the ware taken as 445 calories per kilogramme.

The causes of loss of heat may be divided into six parts :—

(1) Loss due to saggars, supports, etc., used in setting. The weight of the accessories thus used in setting 1 kilogramme of burned ware, multiplied by 0·2 × T, gives the number of Calories lost. In some kinds of ware, the weight of the ware does not amount to one-fifth of the total weight of the contents of the kiln; this shows the advantage, from a thermic point of view, of setting goods open, and of avoiding saggars whenever it is possible to do so.

(2) Loss due to heating the walls of the kiln. This loss is found by multiplying, as before, the weight of the masonry heated by 0·2 T and by the mean temperature at the finishing point of the kiln. From this point of view the most economical kilns are those which offer the maximum space for goods with a minimum of wall surface. This condition is best fulfilled by round kilns and continuous kilns without partitions; in continuous kilns with several chambers this loss may become large enough to outweigh the advantages gained by the continuity of the burning.

(3) Loss due to radiation from the outer walls of the kiln is most difficult to reckon, and should be the subject of direct observation. In well-built kilns, with thick walls, it may not reach 10 per cent; in others it rises to 25 per cent or more. In increases with the exterior surface of the walls, and is most serious in the top of the kilns, especially near the crowns.

(4) Heat lost in gases passing up the chimney can only be accurately determined by determining their volume and temperature at frequent intervals by anemometers and thermometers. As the former work badly in hot gases containing coal dust it is preferable to calculate the weight of gases from the weight of fuel burnt and from their chemical analysis. When these gases have a temperature below 200° C. the heat in them is indispensable to the creating of the draught in the kiln, so that it is only when their temperature rises above this that there is any real loss. The weight of the gases, multiplied by their specific heat and by their temperature, less 200, will be the number of calories of heat passed up the chimney.

An oxidizing atmosphere, by increasing the volume of the circulating gases, also increases the loss of heat, especially in intermittent kilns, but it is often necessary to obtain certain characteristics in the ware to employ a large excess of air.

(5) Loss resulting from a reducing atmosphere. This may be calculated from the analysis of the gases and the fuel, and from the quantity of fuel burnt.

(6) Loss of heat in the fireholes due to imperfect combustion is determined by weighing the ashes and cinders, and by ascertaining the proportion of unburnt material they contain.

(7) In the case of heating by gas, there is an additional loss due to the generation of gas in the producer and transporting it to the kiln.

When the heat contained in the burned ware can be partly utilized, as in continuous kilns, this will reduce the foregoing losses, especially that in the gases passing up the chimney.

The result of adding the number of heat units theoretically necessary for the burning of the goods to those from the different causes of loss just enumerated gives the total heat evolved by the combustion. This may also be found by multiplying the weight of fuel used by its calorific power. By then drawing up a balance sheet showing the relation between the quantity of heat produced by the fuel and that used, the working of a kiln may be studied with advantage, but this problem requires for its solution familiarity with the subject of heating—and even then is difficult to solve.

CHAPTER IX.

Decoration.

Colouring Materials.—The term "colouring materials" in the ceramic industries includes only those fixed or developed by heat, i.e. the coloured mineral matters which resist the necessary temperatures. These owe their colouring power to oxides and salts of one or more of the following metals: Iron, copper, chromium, cobalt, manganese, nickel, uranium, titanium, antimony, gold, silver, platinum, and iridium, vanadium, molybdenum, and tungsten.

These colouring matters may be applied to the ware by five different methods:—

(1) They may be introduced into the body, which then becomes a *coloured body*, and may either remain unglazed or be covered with a transparent glaze.

(2) Coloured bodies or engobes can be used in the form of slip to cover another body (p. 144), in which case they are called *coloured slips*, the ware thus decorated either remaining unglazed or being covered with a transparent glaze.

(3) The body, after being covered with a white or coloured slip, may be covered with a layer of colouring matter made adhesive by covering it with a transparent glaze (*under-glaze colouring*).

(4) The colour may be mixed with the glaze, which thus becomes a *coloured glaze*, being either transparent or opaque.

(5) Lastly, the colour may be mixed with a flux, i.e. made into *vitrifiable colour* and put on the surface of the glaze (*over-glaze colouring*).

Two or more of these methods of colouring may be used simultaneously.

When the colour is mixed with a body or a slip, it must resist the same temperature as that at which the body is burned; when it is placed under or mixed with the glaze it must bear the temperature at which that glaze vitrifies; but when it is put on the surface of a glaze which has been burned previously, the colour need only resist the temperature required for vitrifying the flux added to the colour. In this case, the colour is called *over-glaze* or *colour for muffle fire;* in all other cases it is termed *colour for hard fire.*

These names as commonly used have little value, and cannot be used for classifying the colouring materials, which are best arranged under the names of the compounds or minerals to which they owe their colouring power.

The colour itself is influenced :—

(1) By the temperature of the kiln.

(2) By the atmosphere of the kilns—oxidizing, neutral, or reducing.

(3) By certain colourless materials in the bodies, glazes, or flux.

(4) By the reciprocal action of colours on each other, the colour of a mixture not being necessarily a combination of the colour of the ingredients, e.g. the variable colours produced by oxide of iron in the body (p. 193).

(5) By the alkaline, boracic, or plumbiferous nature of the glaze.

Thus, it is impossible in pottery to give such an accurate classification of colours as in the dyeing industry. Colours cannot usually be made lighter or darker by simply adding white or black to them, but each must be considered separately in order to obtain the various tones obtainable, by varying the proportion of colouring matter added to a definite quantity of body glaze or flux ; or in some cases the thickness of the coloured layer may be increased or reduced.

Colouring Metals.—*Iron* is capable of producing several different colours in bodies ; the more important of these have been described on page 193 ; its action in glazes is different. For relatively low temperatures (below 1000° C.), and in a slightly oxidizing atmosphere, iron oxide gives the colour of the peroxide, i.e. brown and red, which may become violet and approach black in consequence of the presence of iron monoxide ; at such temperatures the iron oxide is suspended in the vitreous mass, with which it does not easily mix. At higher temperatures it may enter into combination, and then gives unstable colours—a bluish-green in alkaline glazes, a brownish-yellow in boracic glazes, and a yellow in plumbiferous glazes. At very high temperatures, ferric oxide under oxidizing conditions remains unaltered except that it assumes a darker shade, but at such temperatures it tends to be reduced, and the resulting ferrous oxide forms silicates which are reddish or blackish-brown or " blue " if much of it is present. When mixed with certain other oxides, iron oxides gives very stable colourings, which are much used.

Red iron oxide is obtained in a pure state by heating iron sulphate ; it then forms a red powder or colcothar, the shade of which depends on the rapidity of heating and temperature. It may also be prepared by precipitating iron salts by ammonia or by alkalies ; the tint then depends upon the salts employed. Iron oxide is found in many earthy compounds, such as ochre, Sienna earth, Thiviers stone, Arminian earth, etc., but these, though much used, are of very variable composition.

Copper oxides are only used in glazes which can be vitrified at a moderate temperature. At high temperatures they tend to be absorbed by the glaze, and even to penetrate into the body itself, forming unpleasant colours. With an oxidizing atmosphere, copper in alkaline glazes gives a beautiful azure blue colour, known by the name of *turquoise blue ;* it becomes intensely green in boracic or

plumbiferous glazes ; with a strongly reducing atmosphere copper monoxide is formed, and gives a beautiful purple-red in alkaline glazes, verging to orange or brown in others. Mixed with other colours, copper oxide produces many shades of green. It is especially used in the form of cupric oxide, a very dense black powder being obtained by heating nitrate of copper, but copper carbonates are also used. "Blue Ashes" and other copper ores are impure and cannot be recommended. Some samples of copper oxide are much too coarse to be used satisfactorily as ceramic colours, and produce unpleasant spotty effects.

Chromium oxides can only be used for colouring white bodies, as the small quantity of iron contained in others always darkens and dirties the colours. In glazes, chromic oxide is generally used. The atmosphere of the kilns influences the colour, yellow chromic acid being formed when the atmosphere is oxidizing, and green chromic oxide when the atmosphere is a reducing one, though this action is much less marked than with iron or copper, and with a sufficient proportion of the colouring matter present it is only noticeable as a slight modification of the shades. Chromium oxide in alkaline glazes gives a bluish-green or a greenish-blue, which is little used ; but in other glazes it produces a beautiful green colour which becomes yellowish when only a small proportion of the oxide is present in an oxidizing atmosphere. Chromic acid produces intense yellows in alkaline or purely plumbiferous glazes, yellowish-greens in boracic glazes, and an orange-red colour in alkaline plumbiferous glazes, at a low temperature. By mixing stannic acid in a glaze containing lime and a small proportion of chromic acid, a red colour varying from rose to purple, and known as a *chrome-tin pink*, is obtained when the temperature is sufficiently high. This colour is not specially due to the chromic acid, because it can be obtained under the same conditions with other substances, but chromium compounds give the best results. The compounds of chromium are also much used with other oxides to produce greens with copper oxide, black with iron oxide, etc.

Chromium oxide is prepared by heating mercury chromate, or by heating potassium chromate with sulphur. Chromic acid is used in the form of bichromate of potash. The use of chromium in pottery only dates from the beginning of the nineteenth century, so that its presence in ware may sometimes indicate the date of manufacture.

Cobalt oxide is a very powerful blue colour ; it may be used for colouring either body or glaze, and resists all temperatures. Added to a glaze it gives an intense blue colour inclining slightly to violet, but light shades cannot easily be obtained pure. When mixed with zinc oxide it gives *ultramarine blue*, and with aluminium compounds it produces a beautiful sky-blue colour. It may be mixed with other colouring oxides to obtain various shades of blue.

In a number of colour factories, cobalt oxide is obtained direct from cobalt ores. It is sold in an almost pure state as cobaltous oxide (CoO), as a dark grey powder ; but more usually cobalt

oxide (Co_2O_3) is used, which contains 85 to 90 per cent of oxide. For ordinary bodies it is often more economical to use the rose-grey cobalt carbonate or the cobalt silicate called *rose cobalt*, which contains only 40 to 50 per cent of the oxide. All these cobalt compounds usually contain some nickel oxide.

Manganese oxide is a powerful colour which, when mixed with iron compounds, gives to bodies a dark brown or black colour, resisting any temperature. In glazes, it forms colours varying from brown to violet, according to the proportion of iron oxide and the composition of the glaze. In alkaline glazes the colour is usually violet, and brown in the boracic ones; plumbiferous colours give intermediate colours; mixed with much iron oxide, manganese compounds produce browns and enter into the composition of most "blacks."

Manganese oxide may be extracted in an almost pure state from its ores in the form of a black powder. For many bodies and brown glazes the ores themselves are used, after having been sorted, washed, and crushed.

Nickel oxide is scarcely ever used, because it gives uncertain and spotted shades, varying from yellowish-green in alkaline glazes, dirty green in boracic ones, and brown-green in plumbiferous ones. It is used together with iron compounds to form shining browns; it also enters into the composition of certain "blacks." It is extracted, in the form of a green or grey oxide, from nickel ores.

Uranium oxide gives a yellow colour with an oxidizing firing, and green or black in a reducing atmosphere. As it is costly it is scarcely used, except in plumbiferous glazes, in which it gives, under moderately oxidizing conditions, a very bright orange-yellow. It is extracted from pitch-blende ore.

Titanium in glazes only gives yellow tints, due partly to the iron always contained in commercial titanic acid.

Antimony oxide forms with lead a compound of a yellow colour. In all other cases it is colourless, but makes glazes opaque. It is usually mixed with oxide of iron, with which it forms a beautiful series of yellows. It is sold in the form of antimonic acid, as an antimoniate of potash, and as antimoniate of lead (*Naples yellow*).

Gold—specially prepared—may be used either as dull gold, which may be made brilliant by burnishing, or, directly, as brilliant gold. If introduced into glazes as a chloride, the colour varies from rose to purple, resists high temperatures, but is costly. By mixing chloride of gold with chloride of tin, a violet-purple precipitate is obtained (*purple of Cassius*) which, in glazes, gives beautiful rose, purple, carmine, or violet colours, but when the temperature is raised above 1100° C. takes a bluish-violet tinge and often disappears.

Silver chloride is added to glazes, produces a yellow colour, but is seldom used. It is occasionally used for silvering, because of the low temperature at which it fuses, and it is often added to purple of Cassius.

Platinum may be used to cover the ware with a layer of dull

platinum, made brilliant by burnishing. Added to glazes as a chloride, it gives a grey colour, which resists high temperatures, but is costly.

Iridium may be introduced into glazes as an oxide, and gives a colour varying from grey to black. It is but little used on account of its high price.

Preparation of the Colouring Materials.—The colours are now made in special works, as each of them requires special methods of manufacture, necessitating, sometimes, long and tedious purification and grinding if they are to be obtained sufficiently pure. Their manufacture needs special knowledge, and it is advantageous to deal with a larger quantity of the raw materials than is used even in the largest pottery ; hence such colours are usually bought ready for use.

"*White*" *Colours*.—All bodies which contain very little or no iron oxide are white, and may be used as white slips. Glazes can only be made white by destroying their transparency. All the ceramic materials which cause opacity—oxide of zinc, lime, arsenious acid, alumina, etc.—are white.

"*Blacks*" can be obtained in different ways, though there is no true black in pottery :—

(1) By using iridium oxide alone, or uranium oxide, also alone, but in a reducing atmosphere.

(2) By a mixture of two oxides, one of which must always be iron or manganese oxide and the other cobalt, chromium or uranium oxide. The mixtures most used are those of iron and chromium oxides, iron and cobalt oxides, and manganese and uranium oxides.

(3) By a mixture of three or four oxides, always including iron and manganese, to which are added cobalt, chromium, and/or copper.

In all these mixtures, different shades are obtained by making one of the colouring materials predominate ; thus, iron gives brown tints, cobalt blue tints, manganese violet tints, and chromium green tints. These colouring materials are used directly in the form of oxides ; but sometimes iron chromate is used, being obtained by precipitating a solution of neutral chromate of potash by a solution of a ferrous salt.

Greys are obtained by lessening the proportion of black colouring materials, but a mixture of iron and cobalt oxides is principally used. Grey is a more difficult colour to obtain than black, because the mixture of colouring matter must be very accurately adjusted so as not to give any yellowish, greenish, or bluish tints, which are very ugly. Platinum gives a beautiful grey of which the only disadvantage is its great cost. For this purpose, the platinum is dissolved in *aqua regia*, precipitated by ammonia, and the liquid evaporated and then calcined so as to produce an extremely fine powder of platinum oxide.

Blues are given by cobalt compounds, such as oxide, carbonate, silicate, or phosphate. Alone, cobalt oxide gives a beautiful blue,

which is slightly violet; by mixing it with zinc oxide, or with alumina, ultramarine or sky-blue colours are obtained. Greenish-blue shades are obtained by adding a little chromium oxide, and violet by the addition of a small quantity of manganese oxide. Cobalt colours should be burned in an oxidizing or neutral atmosphere.

Copper oxide with an alkaline glaze, and burned with a decidedly oxidizing firing, gives a beautiful turquoise blue. Cupric oxide is black, and cuprous oxide red; only the cupric silicate is blue.

Greens are produced by means of chromium or cupric oxide. In alkaline glazes, the tint produced by chromium oxide is changed from a bluish-green to green by adding copper oxide. Bluish-greens are obtained in all glazes from a mixture of chromium and cobalt oxides. The addition of a little iron makes them yellow or brown. A mixture of chromium and nickel oxides also gives a green similar to the greens furnished by copper alone; in boracic and alkaline glazes it is very little used.

Yellows are numerous, the most important being:—

(1) Pure iron oxide, specially used in bodies; at a high temperature it turns brown.

(2) A mixture of antimony oxide and lead oxide to which is often added a little iron oxide.

(3) Pure uranium oxide, the tint of which becomes orange when lead is present.

(4) Titanium oxide mixed with zinc oxide.

(5) Chromic acid, but only in alkaline glazes.

At high temperatures (above 1150° C.) only uranium and titanium can be used.

Reds and Purples.—Rose reds and purples are obtained from iron, chromium, copper or gold, according to circumstances.

(*a*) The red colour due to iron may only be obtained at a temperature below 1000° C.; above this it becomes brown, then blackish. In glazes, its tint depends entirely on the way in which the iron oxide has been prepared.

(*b*) A mixture of zinc oxide, whiting or chalk, and a small proportion of chromic acid, gives a red colour—called *carnation-red* or *pink*—in an oxidizing atmosphere. First, the mixture of oxide and carbonate is finely powdered, a solution of bichromate of potash is added to it, then the mass is dried, calcined, powdered, washed, and dried again. If a suitable quantity of quartz is added to the mixture, shades which are more decidedly red are produced.

The presence of a little tin oxide is also advantageous.

(The success of the manufacture depends on skill in blending and thoroughness in grinding.)

(*c*) By mixing gold chloride with a white, clayey body to which soda has been added, the mixture being first prepared as a liquid paste, and dried, a mass is obtained which has a beautiful purple colour and resists high temperatures, but is very costly.

(*d*) For low temperatures, gold is replaced by purple of Cassius

obtained in the following manner : A solution of gold in *aqua regia* is made, evaporated to remove the excess of acid, and the residue is dissolved in water. Tin is dissolved in concentrated hydrochloric acid, in a separate vessel, evaporated, and the salt allowed to crystallize. This salt is dissolved in water and half the solution is treated with a current of chlorine gas, which changes the tin chloride into dichloride. The two solutions of chloride and dichloride are put together, much diluted with water, and the solution of gold chloride poured into it drop by drop. The precipitate is the colour of wine, and is washed and dried. The method just described can be varied in several ways ; thus sometimes silver is added to gold chloride to make the purple of Cassius redder, as without silver it has a tendency to turn to violet.

(*e*) Copper oxide gives a beautiful red colour, but only in a decidedly reducing atmosphere ; the employment of it is, therefore, limited to certain decorative effects.

Browns are made by iron oxide either alone or mixed with manganese, chromium, cobalt or nickel oxide, which give them the most varied shades.

Violets are made by (i) adding manganese oxide to an alkaline glaze ; (ii) mixing cobalt oxide with one of the red colouring materials already described, especially with pink ; and (iii) mixing purple of Cassius with a flux that is rather more alkaline than plumbiferous ; silver chloride must not be present.

All the colouring materials should be as finely powdered as possible and thoroughly well mixed, in order to give a uniform colour and one that is regularly distributed. This grinding is done either by mortars (for very small quantities), or by using the processes employed for powdering the glaze materials (p. 181).

Properties of the Colouring Materials.—At relatively low temperatures, the colouring materials may combine together to form salts, the colour of which is not related to the colours of the component substances. Thus, antimony oxide, and lead oxide, both of them white, form lead antimoniate which is yellow. In these combinations the oxides having the symbol MO (M being any kind of metal) act as a base, those with the formula MO_2, MO_3, or M_2O_7 are acids, whilst those having the symbol M_2O_3 act according to circumstances, as acids or bases.

Iron monoxide, manganese oxide, cobalt oxide, and the red copper oxide are basic, while the oxides of antimony and chromium are acids. Among the salts which can be formed may be mentioned : Iron chromate and antimoniate, the manganates of cobalt and chromium, manganese, chromium, cobalt, etc., ferrates. By adding other colourless metallic oxides to the colouring matter properly so called, other coloured salts are obtained ; the colourless oxides which have been mentioned among the raw materials for the glazes are the oxides of tin, zinc, and lead. The first, which is always acid, gives stannates, the second usually produces zincates, and the third makes bases when in the form of monoxide, and

plumbates when in the form of red lead. Chromium stannate, iron zincate, lead antimoniate and chromate, etc., are also used.

Among the alkaline earthy bases—which may also be found in colours—lime, baryta, and magnesia constantly act as bases, while alumina more often plays the part of an acid, as in barium chromate and cobalt aluminate.

Alkalies (soda and potash) are always basic, while boracic acid and silica are always acid.

The number of combinations which may be formed explains the numerous variations in the shades of pottery colours, as well as the impossibility of mixing several colours in order to obtain a middle colour.

When the colouring matter has to be fixed to the surface of the glaze (as in over-glaze decoration) a flux—i.e. a material which will form a vitreous material with the colouring matter—must be added to it; it is then easy to produce almost any desired colour; this and the low temperature needed for baking them explains why the series of vitrifiable colours sold by colour manufacturers is so large and comprises almost all imaginable shades.

When a colouring material is mixed with a body or glaze, the composition of the latter not being dictated solely by considerations of colour, the range of colours is more limited, as the higher temperature needed for burning the body or maturing the glaze modifies the colour of the different substances present. For instance, the acid properties of silica develop as the temperature increases, so that silicates are progressively substituted for antimoniates, ferrates, zincates, stannates, manganates, plumbates, aluminates and, at the temperature used for burning porcelain, the silica, together with boracic acid, if present, is the only acid element in the material.

It is advisable to retard the action of silica by forming compounds that resist it as much as possible, of the colouring matter and the other elements of the body or glaze. The most stable combinations, from this point of view, are those with the composition of spinels, and are formed by the combination of a protoxide and a sesquioxide with the general formula $RO \cdot M_2O_3$. Some colouring materials, however, are not capable of combining with fluxes, glaze or body, but either make them opaque—as in the case of several colours for over-glaze painting—or remain unattacked at high temperatures, as gold and platinum.

The introduction of colouring matter into bodies or glazes usually increases the fusibility. Chromium oxide is the least fusible, then red iron oxide, manganese, and uranium, and, lastly, the oxides of cobalt and copper. The composition of the body or glaze must, therefore, be modified so as to render it more refractory.

With the exception of copper oxide, all colouring oxides make compounds which expand less than that of lead oxide (p. 198). This property makes it difficult to obtain certain colours, especially turquoise blue, from copper, which do not peel from the ware.

Processes of Decoration.—By employing, separately or simul-

taneously, several decorative processes, most varied results can be obtained, thus allying the art of sculpture to that of painting.

Decorative Moulding of the Body.—In Chapter V only ordinary moulding was mentioned, i.e. that used to produce a number of similar objects, without taking account of the purely decorative details of manufacture. To complete what has been already stated, from a decorative point of view the moulding may have two objects : (1) The creation of a unique decorative object ; (2) the decoration of objects manufactured in large numbers by moulding.

The moulding of an original decorative piece of pottery must naturally be modelled by hand, or by forming it on a potter's wheel, and finishing it by turning, the processes employed depending entirely on the nature of the material and on the form of the piece. Modelling by hand needs somewhat plastic clays ; this is always the case with terra-cotta and stoneware, and usually applies to fine earthenware ; porcelain bodies are, however, much less plastic, and present such difficulties that agglutinants (size, dextrine, etc.) must be added to some of them.

It is often convenient, and sometimes necessary, to mould the parts in high relief separately, and to join them afterwards to the principal object. The ease with which this is done makes possible the modelling of very much under-cut objects and those with thin and delicate raised pieces, such as ware with raised wreaths and medallions.

The amount of moisture in the body is of great importance. During the whole of the modelling the body must be kept from drying by being surrounded with damp cloths or damped with sponges, but this inconvenience may be avoided when the body can be carved after it has been allowed to harden, as it then lends itself to exact working in which the joints can be lost, the thicknesses be lessened, and the contour be made accurate. In lean bodies, this carving replaces modelling to a great extent, as the piece can only be formed more or less roughly in the first instance. In this way it is possible to attach very thin parts in high relief, which would get out of shape if they were put on when the ware is still plastic.

It is very important to notice that objects having thick massive parts and other parts which are much thinner, cannot be readily dried and fired, and it is then necessary to hollow out the more bulky parts. Sometimes, after the modelling is finished, the part to be hollowed out must be taken off in two or more pieces by a metal wire, or with a thin blade. Each part is then hollowed out separately, the whole stuck together again, and the joints are cleaned off. An allowance must be made for the shrinkage which all bodies undergo on drying and firing (about 10 per cent linear, or 1 in. per linear foot in plastic bodies), the dimensions of the object being increased proportionately before modelling.

Decoration by hollow designs, frequently repeated, may be made with stamps having the design cut in relief. A slab of paste is prepared, the design is formed by the stamp, trimmed, and pressed

against the body when it is slightly firm. When this decoration forms a band in which the same design is constantly repeated the stamp is replaced by a revolving wheel. These two processes in decoration are called *stamping* and *beading*. Engine-turning (or dicing) may also be used, as in other industries. Large plaques may be ornamented by a design repeated indefinitely, by passing them under an engraved cylinder.

When the body is nearly dry, the surface can be polished and its hardness increased by rubbing it with a piece of horn.

In certain cases the glaze may form part of the moulding of the body. Thus, it is possible to make plaited objects which would easily break if fired direct, but if dipped into a glaze before firing, they are made strong, as the glaze fastens the pieces together. Small hollows may also be made in the body and afterwards filled with glaze, so as to form a special style of decoration.

Colouring a Body.—It has been shown in the chapter on firing that iron oxide in the clay can give different colours to the body. By mixing other materials with a body, coloured bodies of different shades may be obtained. The colouring matter should be in the form of an extremely fine powder, and must be very carefully mixed with the body if a uniform colouring is desired. Sometimes, to economize the colour, only the surface of the body is impregnated with it, but this process seldom gives uniform colours, and it is better to apply a coloured slip to the ware.

In order that the colours may be stable and not removed by washing, it is necessary that the temperature at which they are burned should be sufficient to ensure their combining with the body, otherwise only a fritted colour should be used.

White bodies are made of materials which do not contain iron oxide. It is almost impossible to avoid its presence entirely, but, notwithstanding a small proportion, white bodies may be obtained at a moderate heat ; with vitrifiable bodies a reducing atmosphere in the kiln must be used, so as to reduce the red iron oxide to the bluish ferrous oxide which is complementary in colour to the unreduced oxide, and produces a bluish-white body.

Black (or rather what passes for black) is usually obtained from a mixture of iron oxide and manganese oxide. According as one or the other preponderates, the " black " approaches brown or violet. If a body is ferruginous, it is sufficient to add manganese oxide. For fine wares, iron oxide, to which a small quantity of cobalt oxide is added, is sometimes used, or a mixture of the iron, manganese, cobalt, and chromium oxides may also be used.

A kind of black ware may also be produced by firing with a strong reducing atmosphere so as to reduce the iron oxide and deposit particles of carbon in the pores of the ware. This carbon results from the decomposition of the hydrocarbons and carbon monoxide given off from the gases of the furnace.

Greys are obtained with a smaller proportion of the oxides of iron and manganese, but in order to obtain very light shades it is

necessary for the body to be only very slightly ferruginous. Beautiful shades are obtained by mixing iron oxide with a small quantity of cobalt oxide. For fine vitrifiable bodies, iridium oxide and platinum chloride may also be used, either separately or together.

Blues can only be produced with white bodies to which cobalt oxide is added. The shades thus obtained depend not only on the proportion of the colouring oxide, but also on the quantity of alumina in the body. If this is large, the colour is sky-blue, if the body is silicious, the shade approaches indigo. This latter colour (*Persian blue*) may be obtained in silicious bodies by first fritting cobalt oxide with its own weight of zinc oxide. Silicious bodies can be coloured sky-blue by first fritting cobalt oxide with alum.

Greens are obtained by mixing chromium oxide with a white body, as free from iron as possible. Various shades are obtained by altering the amount of colouring oxide, and by adding a little cobalt oxide for bluish-greens. Sometimes, also, nickel oxide is used and, alone, gives a bright green, though it is uncertain; if mixed with a little cobalt oxide it produces an olive-green.

Yellows, orange, and yellow-brown are produced in terra-cottas by iron oxide, using natural clays. In vitrified bodies, iron oxide only produces a yellow body when the atmosphere is oxidizing; if it is reducing the colour changes to a greenish-grey.

Reds are also obtained from iron oxide, but they do not resist a high temperature. Intense yellows and reds are very difficult, if not impossible, to obtain in vitrified bodies, though if bichromate of potash be fritted with pure alumina and this frit, finely powdered, is added to the body, a rose colour or pink is formed. The addition of a small proportion of cobalt oxide turns this rose colour or pink to lilac.

Browns are produced by iron oxide at a somewhat high temperature. For ferruginous bodies that only need a moderate heat, brown is easily produced by the addition of a little manganese oxide. In fine white bodies, a mixture of iron and chromium oxides or iron chromate is used. A mixture of manganese and chromium oxides can likewise be used, or a frit of zinc and chromium oxides obtained by heating zinc sulphate with chromium oxide.

Violets can be obtained only with difficulty—usually with manganese oxide or with chromium and cobalt.

Coloured Slips and Engobes.—The term "slip" or "engobe" is applied to a body put on the surface of another body which has been previously moulded. Coloured bodies may naturally be used in this way to decorate articles made of other bodies, this decorative process being used either for economy, by colouring only the surface, or for decorating the surface of the body with paintings and reliefs in different colours. In the first case, the slip should be spread over the whole surface, or only on the inside or the outside of the piece, the ware being made of dry body or of biscuit. The methods employed for applying the coloured slip are the same as those mentioned in Chapter V for colourless slips, and need not be repeated.

In the second case, the slip is usually applied with a brush to the raw paste, or to biscuit, by employing the methods used for oil or water-colour paintings; this method of decoration has been termed *barbotine*. The decorated ware, when dry, may be baked if it is to be left rough, or it may be first coated over with a colourless glaze which must be transparent, and then burned. The background, or the painted parts only, may also be coated with glaze. In *barbotine* it is wise to use only a small quantity of clear colour without giving too much modelling to the design, and without trying to imitate oil-painting. A dull or slightly monotonous appearance is avoided in this style of decoration by making the background more vivid than the painted parts, or *vice versa*.

By making the slip slightly stiffer, it is possible to apply relief decoration with a brush, and afterwards touch up the edges and the higher parts by carving with small tools.

The pasty slip may also be placed in a vessel with a very narrow spout and allowed to fall out, drop by drop, on to the ware, in such a way as to form round balls, lines, or rosettes; this method of decoration is known as *pastillage* or *slip decoration*. By using a vessel with several compartments filled with slips of different colours, and a number of spouts side by side, a multi-coloured slip may be allowed to trickel on to the ware and thus produce *marbled effects*. By covering over the whole article with a glaze, imitations of different marbles may be produced.

In certain cases, especially for paving tiles, cells which can be filled with slips of different shades are sometimes arranged during the moulding of the surface of the piece; these cells are filled with coloured slips, the surface being afterwards levelled by means of a knife; this is known as *encaustic* decoration.

Slips may be used for decorative purposes by incrustation, as described on page 145, small moulds, divided by partitions of thin tinplate, which form the outlines of the design, being used, and filled with dried paste of various colours. After the separating partitions have been removed, the coloured slip is covered with a powder of the composition of the ordinary slip, and the whole joined together by great pressure. A fuller description of these last two processes will be found in the articles devoted to the manufacture of tiles (pp. 379, 420); this is also known as *encaustic* decoration.

Under-glaze decoration consists in colouring the raw or burned bodies with or without a covering slip, the whole being covered with a colourless transparent glaze, which develops and fixes the colours. This must not be confused with under-glaze barbotine painting, in which the colouring matter is mixed with the slip, as in under-glaze painting it is the glaze into which the colours penetrate under the influence of heat.

When the whole article is to be uniform in colour, the method of applying the colour described in Chapter V (p. 145) is used, the colouring matter, powdered very finely, being mixed with a sufficient quantity of water, to which a little gum-arabic, treacle, or glycerine

has been added to make it more adhesive. When biscuit ware is to be decorated in this way, it is often best to make it less absorbent by soaking it in water or in a gummy or albuminous liquid, the article being heated sufficiently to make the body absorbent again before the glaze is applied.

Dipping may also be used to produce marble or band effects. The colours ground up with water or spirit are put in a bath of gum tragacanth dissolved in water and stirred. The warmed piece is then dipped into the bath, and absorbs the colour.

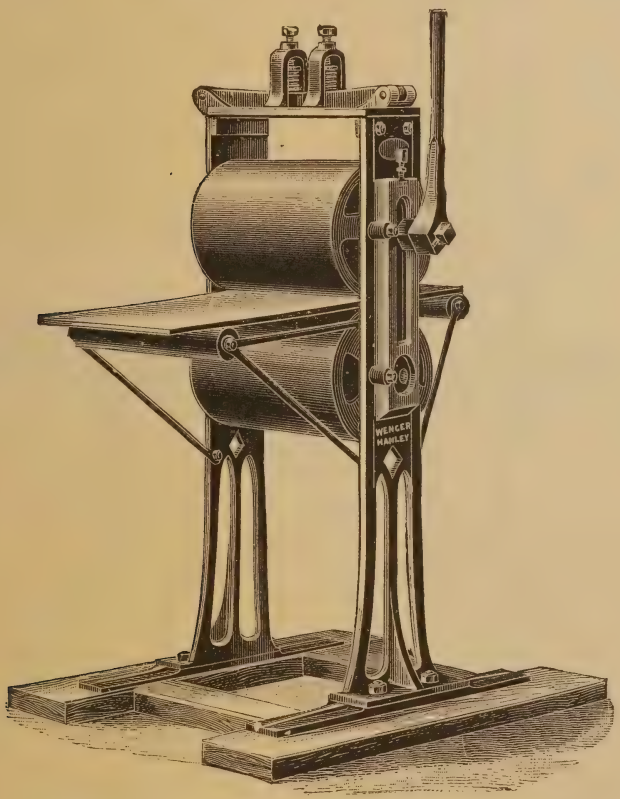


Fig. 174.—Printing press for decorating pottery.

If it is desired to produce a pattern, the colours may be applied with a brush or by printing.

For under-glaze painting with a brush, the colours, ground to an impalpable powder, are mixed with gum-arabic or spirits of turpentine on polished glass, either with a muller or with a pallet knife, and are applied with a brush, as in oil painting. The shading is obtained by putting tints over one another. The ware thus decorated

is afterwards dried, and coated with glaze by one of the methods already mentioned.

In decoration by printing, copper plates beaten out with a hammer are used and carry the design to be reproduced. The engraving on the plates should be done by stippling, using the graver as little as possible. The colouring materials, powdered very finely, are mixed very carefully with printing oil. This latter is made by heating linseed oil with a little resin, tar, or gum. The mixing is done with a muller on an iron plate heated to 150° C., or in a special apparatus. This mixture is spread over the engraved plate with a

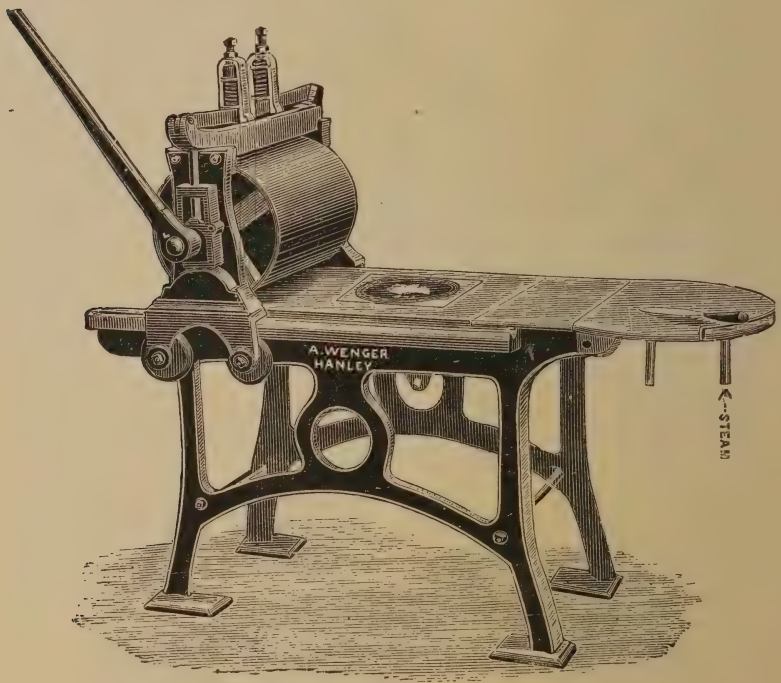


Fig. 175.—Steam-heated printing table.

spatula, care being taken to force it into the hollows by means of a dabber; the excess of colour is then taken off and the plate is cleaned. The plate having been thus prepared, it is covered with a sheet of thin hemp paper, previously soaked in a solution of soft soap, and passed under a press to print. Then, after having placed it on a plate heated by steam, the paper is detached, and on it the colour remains; the part containing the design is cut off and applied to the pottery to be decorated, by rubbing the paper with a roller. At the end of several hours, the decorated article is steeped in water and the paper detached with a sponge. The impression adheres to

the ware, which is afterwards dried, heated to 150° C. or 200° C. to evaporate the oils, and is then covered over with glaze and burned. Only monochrome designs can be printed by this process, and the decoration may be completed by painting with a brush, or a process of chromo-lithographic printing may be used, as described on page 271.

In under-glaze work, the colours must resist the temperature used for burning the glazes in which they are vitrified. The colouring materials used have been described in the previous chapter. The background colours must be somewhat liquid ; they are used either for colouring the whole piece, taking the place of a slip, or else to colour only certain parts, such as the edges of plates, or for making bands. They are difficult to apply if a uniform tint is desired, as for deep colours it is necessary to make them very thick and to run the risk of their not being entirely dissolved by the glaze, in which case they remain dull and are liable to become detached from the body.

The colours applied with a brush or by printing are more numerous and need fewer precautions. Their composition depends on the temperature at which the glazes fuse, and they should be sufficiently stable to resist the action of the silica as much as possible. They are often mixed with some of the body, especially for porcelain.

Coloured glazes are prepared like ordinary glazes, but with the colouring matter added to them. This method of colouring pottery gives most brilliant colours. According to the colour used, the glaze must be alkaline, boracic, or plumbiferous. After having been finely powdered, water is added to make a paste of the desired consistency. Coloured glazes are usually applied to the burned body or biscuit.

If the whole ware is to receive a uniform layer of glaze, the latter is applied by one of the processes used for colourless glazes (p. 183)—usually either by dipping or dusting, any parts of the body which are not to be covered, having been first coated over with gum-arabic or with some other viscous material. The glaze cannot adhere to the painted parts but falls off during the burning leaving the *reserve* bare. When these reserves are to be ornamented with glazes having different colours from those of the background, they may be mixed with oil and applied with a brush ; at the time of dipping the glaze of the background, which is prepared with water, does not adhere to the greasy parts. When the glazes are transparent, it is sometimes difficult, by dipping, to get a perfectly regular thickness, though this is necessary to give the whole piece a uniform colour ; it is then preferable, especially for large surfaces, to use the method described under Spraying (p. 185).

At other times, it is advisable for the glaze to differ in thickness in different parts of the ware, so as to obtain darker or lighter shades. For this purpose, a hollow ornament is arranged in the moulding, or by engraving on the body. When the glaze is applied by spraying, the thickness of the colour can also be varied.

Coloured glazes may also be applied with a brush to the burned body, but they tend to mix together when they are vitrified. To prevent this trouble, the edges of the design are drawn in fairly high relief with a black glaze that is less fusible. The cells thus made are afterwards filled with different colours. The ware decorated by this process has been called *cloisonné enamel* ware, in consequence of its likeness to certain enamels on metal known by the same name.

In **over-glaze colouring** the colour is placed on the glaze, either before or after the latter has been burned. In the first case, the glaze is nearly always an opaque white enamel, which at the moment of its vitrification dissolves and fixes the colour, which must, naturally, be able to resist the temperature used for burning. In the second case the colour should previously have been mixed with a flux, to form a vitrifiable colour which changes to a glass at a temperature below that required to fuse the glaze to which the colour adheres.

The application of the colours to *raw enamel* can only be made with a brush, and needs great skill, because of the thinness of the glaze. The colouring matter is diluted with water, to which glycerine may be added if the slip is absorbed too rapidly. The glaze being usually stanniferous or plumbiferous, it is wise to take account of any action that the oxides of tin and lead may have on the colouring matter. The reduction of the number of shades in consequence of this, added to the difficulties of application, make this kind of decoration unpopular, in spite of its harmony and depth.

Over-glaze painting with vitrifiable colours is, on the contrary, a method of decoration which is very much used, not only in potteries but also by amateurs. Thanks to the low temperature at which the fluxes vitrify, an extremely rich pallette of colour is possible, and at the same time all the numerous difficulties presented by the other methods of colouring which have just been described are avoided. It is only fair to add that the colours are dull, and that the decorative effect cannot be compared with that of the colouring used for hard-firing.

In order to manufacture *vitrifiable colours*, suitable mixtures of the colouring materials must first be made. They are usually combined together by dissolving the colouring oxides in hydrochloric acid, and precipitating them with carbonate of soda ; the precipitate is washed, dried, and then calcined at a red heat. The flux is a compound of white sand, red lead, and borax in varying proportions, melted in a crucible and poured out as soon as it is completely fused. When cooled, it is mixed in a suitable proportion with the colouring matter, and the whole powdered very finely. Some of the most important potteries make their own vitrifiable colours, instead of buying them prepared for use.

For *over-glaze painting*, the vitrifiable colours are usually mixed with spirits of turpentine. They are applied with a brush, in flat layers over one another, as in water-colour work. To obtain dark colours, it is sometimes unavoidable to give to the layers thus put

over one another such a thickness that the colour would scale off in firing. The article is then put into the kiln and fired ; it is then repainted with the vitrified colour and burned again. This operation can be repeated several times, until the desired effect is obtained.

The backgrounds can be painted in a single shade in the same way, but with a badger brush, and the layer is afterwards stippled up with a short-haired or polecat brush. The piece can also be coated with boiled linseed oil, with the addition of a little resin, to which the dried and powdered colour is applied by dusting.

The merchants of vitrifiable colours sell these ready for use, so that it is easy for anybody to become a pottery painter, by buying white glazed ware, painting it and having it burned in a pottery.

For a large number of similar articles, the design is printed either in monochrome, as already described, or by *chromo-lithographic printing*. For this, the original design in outline is traced with lithographic ink and transferred to stone, a sufficient number of copies being transferred to as many stones as there are different colours. The draughtsman then fills in the outlines thus produced with a brush in lithographic ink, each stone naturally being painted only on the parts corresponding to its colour, and the rest of the design being afterwards wiped off. The stones are then washed over with acidulated water, which fixes the ink and gives a slight relief to it. The surface of the stone is then passed over with a wooden roller covered with leather and soaked in varnish, the varnish being left on the parts covered in ink. A sheet of paper sized with gum-arabic or dextrin is next spread on the stone, and the whole passed through a printing machine. From this, the paper emerges decorated with the varnish ; it is raised, turned over, and dusted with vitrifiable colour, any excess of colour being taken off with a soft brush after the varnish has been allowed to dry. The same process is repeated in printing the second and following colours, care being taken to fix the position of the sheet of paper, so that the different colours may occupy exactly their right places. Usually each design is reproduced several times on the same stone in such a way as to use all the surface. In some factories the lithographic stones are replaced by suitably prepared zinc plates. The chrome-lithographic sheets thus manufactured are kept until wanted. They can also be bought.

The colour is transferred to the ware in a very simple way. The design having been covered with copal varnish and resin dissolved in spirit, it is applied to the ware first with a roller, then by stippling, so as to remove any air bubbles. When the varnish is hard, the pottery is plunged into water, which dissolves the gum or dextrine from the paper, so that the paper comes off readily, leaving the colour adhering to the ware. The piece is washed, dried, and heated in a stove to remove the varnish, and is then put into the kiln.

This chromo-lithographic process is largely used for ornaments decorated with flowers, animals, and figures, though for the last-named it is better to use *photo-lithography*, i.e. by using photographs

in the place of drawn designs. A plate of bichromated gelatine is covered over with a negative of the photograph that it is desired to reproduce and exposed to the light. When sufficiently exposed the plate is soaked in water, which dissolves the portion of the bichromate not affected by light and leaves the design in relief. The surface of the gelatine plate is inked by a roller, then covered with a sheet of paper, the whole put in the press, and thus a reproduction of the photograph is obtained on the paper; this is afterwards transferred to stone and treated in the same way as in the ordinary process of chromo-lithography.

The colours thus obtained by printing on the glaze are rather dull on account of the small quantity of colour it is possible to apply by chromo-lithography. Sometimes they may be made more brilliant by burnishing them, after they are burned, with a stipple and very fine sand, or by a mechanical arrangement in which the ware is pressed against rapidly rotating brushes impregnated with emery powder.

Decoration with Metals.—Gold, platinum, and silver are the only metals which, while being malleable, resist the action of oxidation and heat, and can be used in a metallic state.

Metallic *gold* can be used under glaze, a piece of gold thicker than those intended for gilding being cut to form a part of the decoration, and fastened to the burned body by means of resin or with a decoction of quince-pips. To brighten it, the body may be first covered with a thin glaze, dusted over with grains of sand, which, when burnt, is covered with gold leaf, and this is stippled with a short-hair brush, which gives it a granulated surface. The glaze proper is applied afterwards and burned in the ordinay way. The gold must not contain any copper, as this would oxidize and would colour the glaze green. The temperature for vitrifying the glaze must be well below 1045° C., the temperature at which the gold fuses.

Platinum may be used in the same way. *Silver*, being more easily oxidized and more fusible, is more difficult to use.

This method of decoration is only used in exceptional cases, but *over-glaze gilding* is very frequently used. In this process, the gold is not in the form of leaf, but of an impalpable powder. To produce it, the metal is dissolved in *aqua regia*, and precipitated either by a dilute solution of ferrous sulphate or of mercurous nitrate. In both cases, a precipitate of metallic gold is formed, and this is separated from the liquid by decanting, washed several times in boiling water, and dried at a temperature below 100° C. Gold powder prepared with mercury is more bulky, and consequently more economical and more used than that precipitated by the iron salt.

To fix the gold powder thus obtained to the ware, it must be mixed with a flux; a solution of bismuth nitrate in nitric acid being employed. This salt being precipitated by water, about half its weight of borax is added to it and the mixture dried, then it is added to the gold powder in the proportion of $\frac{1}{12}$th or $\frac{1}{15}$th. In

certain cases, a little lead borate is added to increase its fusibility, and a little balsam, resin, or other viscous material may be added to increase its adhesion to the ware prior to the fusion of the flux. After being burned, the vitrified gold is dull, but may be brightened by burnishing it with burnishers of agate, hematite, or bloodstone, or by rubbing it with fine sand. It should always be rubbed in the same direction, so as not to scratch the gilding, and some liquid such as vinegar should be used to make the rubbing easier when burnishers are used. Certain parts may be burnished while others are left dull, so as to obtain contrasting effects.

Platinum may also be used over glaze in the same manner as gold, by dissolving it in *aqua regia*, and precipitating it by means of carbonate of potash and sugar, or by caustic potash and alcohol. The black precipitate of platinum is dried, calcined at a dull red heat and used like gold.

Silver is obtained in the form of a powder by precipitating the chloride with zinc in the presence of sulphuric acid or by decomposing silver nitrate with copper wire. The precipitated silver is dried and the powder used in the same manner as gold.

The preceding metals may also be mechanically reduced to a powder by grinding them on glass with honey, but this process is very troublesome, and is now seldom used.

Decoration with Metallic Lustres.—A lustre-effect is formed when a very thin layer of very finely divided metal shines with iridescence after it has been heated at a rather low temperature, or has been burnished. The metals used are gold, platinum, silver, copper, iron, and lead. Lustres are always applied over glaze, and the more brilliant the latter, the more the lustres shine. Numerous recipes for obtaining lustres cheaply exist; those most used are *bright gold* or *Meissen gilding*, which, when burned, has a metallic brightness, but does not wear so well as dull gold made bright by burnishing as just described. The ware is treated by liquids sold by certain colour merchants, who carefully keep their recipes as manufacturer's secrets. The prices are so reasonable that potters do better to buy lustres than to try to manufacture them for themselves.

Fulminating gold, obtained by precipitating chloride of gold with ammonia, may also be used. The precipitate is ground, while still damp, with essential spirits of turpentine or oil of lavender. The liquid is applied directly to the ware, no flux being used. The precipitate must be prevented from drying before firing, as when dry it will explode violently with the least touch.

Burgos lustre only differs from the preceding ones in the larger quantity of spirit and the less gold used; 20 per cent of metallic tin is often present.

Platinum Lustre.—A concentrated solution of platinum chloride is mixed with essential oil (oil of lavender), and the liquid is spread on the ware with a brush. The lustre obtained has a steely appearance, but is nearly opaque.

The preceding lustres may be burned with an oxidizing fire, but

the following ones must be burned in a distinctly reducing atmosphere.

Silver lustre is made by fusing silver chloride with a plumbiferous flux; the yellowish glass is powdered; and after the addition of spirit, and sometimes bismuth, it is applied with a brush. When burned it gives the ware a metallic appearance with a yellow sheen or a rich iridescence, which has given it the name of *cantharides lustre*.

Various lustres may be manufactured containing salts of silver, copper, iron, and lead. Copper gives a golden colour, silver a steely tinge, iron produces red. The metals are usually in the form of sulphides; sometimes a little lampblack is added to help in reducing them. The colours are thinned with vinegar or with spirit, and applied with a brush. Lustres having the most varied reflections may be purchased ready for use.

Various methods of decoration used, but not readily classified, include the following:—

Crazing is ordinarily a defect which arises from excessive contraction of the glaze, but may be used as a means of decoration. The difference in contraction between the body and glaze must be fairly great, so that the latter may be cracked in a large number of little lines, forming a regular network. The ware may be rubbed with a suitable colour, which penetrates the cracks, any surplus colour is then removed by further rubbing; the ware is next covered with a second, more fusible, coloured glaze, which protects the cracks, which show up clearly by their different colouring. The Chinese excel in this method of decoration.

Streaks are produced by too long a heating or too high a temperature, which causes the glaze to run down. This defect is used as a means of decoration, particularly for tiles and vases, the glazes used being made more fusible by the addition of borax; they are usually coloured and applied to biscuit or to another more refractory glaze. Marbled effects may thus be obtained.

Flamed ware is produced by the use of colouring materials which change colour according as they are burned in an oxidizing or reducing atmosphere. This is especially the case with copper oxide, which, under oxidizing conditions, has a green colour in boracic and plumbiferous glazes, and blue in alkaline glazes, but in a reducing atmosphere gives a red colour (*rouge flambe*). By alternating the composition of the atmosphere, a succession of oxidizing and reducing effects may be produced, and capricious colours, the exact shades and arrangement of which are quite unforeseen, especially if the temperature is rather high, are produced in the ware. The copper oxide may partially volatilize and reveal part of the body through the glaze.

Flowing Colours.—If the ware, decorated with a design in certain colours—particularly those containing cobalt—is heated in an atmosphere containing volatile chlorides, the latter may attack the colour and change it into a volatile chloride, which spreads on to

the surrounding white body and is decomposed there by contact with the silica, giving a light graduated tint, darker in the neighbourhood of the design and forming a sort of halo round it. The chlorinated atmosphere is usually produced by putting in the saggars little balls, about $\frac{1}{2}$ in. in diameter, made by dissolving white lead in hydrochloric acid. When the glazes employed are so rich in lead that it would be inadvisable to increase the amount of lead in them, a mixture of six parts of sea salt and four parts of saltpetre may be used.

The principal colours which thus form volatile chlorides are cobalt oxide, which produces a blue, nickel oxide yields a brown, copper oxide with a low temperature produces green, and iron oxide gives a disagreeable yellow. This process of decoration is used chiefly for earthenware. For success, the saggars must be carefully luted, and should have been coated internally with flint.

Sgrafitto is a form of decoration in which a body is covered with a material of a different colour, and the design is produced by scratching or cutting the superficial coating so as to reveal the body beneath. Thus, when a coloured glaze has been applied and is dry, it may be removed in places, or it may be engraved so as to allow the body or glaze underneath to show. The friability of the raw glaze makes this operation easy, but it requires a certain amount of dexterity.

An effect of *being covered with pearls* on the surface of a piece of pottery may be obtained by first covering it with a thin layer of a colourless glaze, over which, while still damp, grains of sand or of burned ware coarsely powdered may be dusted. When burned, the surface is again coated with another glaze, which forms around each grain a little vitreous drop, resembling a pearl. By replacing the sand by a more finely granulated body a decorative effect is obtained, which has been called *moss*.

Small glass objects—*pearls*, *spangles*, *jewels*, etc.—may be fixed to the body or to a first glaze by means of resin dissolved in spirit, with some flux added to it.

The burned bodies may be decorated with *vitrifiable crayons* made of vitrifiable colours, which are used like ordinary pencils. They are sharpened by rubbing them on glass paper.

Ceramic photography, which must not be confounded with photolithography (p. 271), lends itself to reproduction. A sheet of ground glass is covered with bichromate of potash, dextrin and grape sugar dissolved in water, and exposed to the light under a positive. If a negative is used, the sheet of glass must be covered with an aqueous solution of perchloride of iron and tartaric acid. Specially prepared plates may be purchased, and are usually superior to the "home-made" ones. The plate is "developed" by washing in water or other suitable solution, whereby the chemicals which have not been acted upon by the light are removed, leaving the design in low relief. The surface is dusted over with a vitrifiable colour,

the excess of colour is removed, the glass coated with a layer of normal collodion, and plunged into some slightly acidulated water. The collodion comes off, taking with it the vitrifiable colour, which is applied to the ware. The collodion is removed by heating the ware to which it is applied, or it may be dissolved in a solution of alcohol, ether and oil of lavender.

Cold decoration is a term applied to the use of paint, varnish, lacquer, etc., without the application of heat. Such decoration, though applicable to pottery, is not included in the term ceramics, and need not be more fully described.

Burning the Colours.—What has already been said in relation to bodies and glazes will naturally apply to burning colours. As with colourless glazes, the agreement between the body and the glaze must first be studied and the directions previously given must be followed. The maximum temperature for burning as well as the working of the fire require most minute attention. The colours must not be exposed too long at the temperature for fusing the glaze or flux, because of the ease with which some of them volatilize. This volatilization is increased when the wares are placed in the kiln by the side of unglazed bodies, being greater with over-glaze colours and coloured glazes than with under-glaze colours. The metallic oxides on one piece of ware may stain a neighbouring piece when they are too close together in the kiln, or when they are of different colours.

When the burning temperature is very high the articles (unless very large) are placed in saggars in ordinary kilns ; in all other cases muffle kilns are used, the goods being placed on slabs. For burning vitrifiable colours at a relatively low temperature, the fire-clay slabs may be replaced by iron plates. In addition to the methods for measuring temperature already described (p. 246), *tests for gold* are often used for burning vitrifiable colours. These tests consist of a piece of body covered fairly thickly with a gold colour. The tint varies with the temperature, as shown by the following table :—

GOLD-COLOUR TESTS FOR TEMPERATURE.

Colour of the Test.	Approximate Temperature.	Uses.
	Degrees C.	
Red-brown	650	For burning lustres.
Red	800	,, ,,
Rose-purple	900	For burning vitrifiable colours.
Rose-violet	920	,, ,, ,,
Violet	950	,, ,, ,,
Pale violet	980	,, ,, ,,
Colourless or only slightly violet	1000	For burning dull gold.

The atmosphere in muffles used for burning colours should usually be oxidizing, and there should be no cracks through which the gases from the fire can enter. For copper-reds and certain lustres, on the contrary, a decidedly reducing atmosphere is necessary, and a small ordinary kiln is then preferable, the ware being set in open saggars.

CHAPTER X.

TERRA-COTTA.

The term *terra-cotta* is applied broadly to any articles made of clay and afterwards baked or burned in a kiln or oven, but it is usually restricted to articles of a comparatively coarse nature, and particularly to bricks, roofing tiles, and the so-called architectural terra-cotta, though other unglazed articles made of coarse clay are often included.

(*a*) Bricks.

The bricks used by the Egyptians, Assyrians, and Romans were noticeably larger than those manufactured at the present time, and were usually in the form of slabs. The following table shows the dimensions of some of the best-known types of bricks :—

	Dimensions in Inches.		
Ancient Bricks.			
Roman	23·5	23·5	2·2
„	17·5	17·5	2
„	8·4	8·4	1·6
Languedoc (11th and 15th century)	1·3	9·9	2·4
Modern Bricks.			
France, Burgundy	8·8	4·4	2·2
„ Marseilles	8·8	4·4	2
„ „	8·8	4·4	2·8
„ Paris (Vaugirard)	8·8	4·4	2·4
„ „ „	8·8	4·4	2·6
„ largest	9·1	4·4	2·8
„ smallest	7·9	4	2
„ type proposed by the Pottery Union	8·8	4·2	2·2
„ „ „ Architects of the North	8·8	4·2	2·4
Germany	9·8	4·9	2·6
England, largest	10	5	3
„ smallest	9	4·5	2
Austria, largest	11·6	6	2·6
„ normal	9·8	4·9	2·6
Belgium, smallest	7	3·4	1·8
United States	7·8	3·9	2
Mexico	10·2	5·1	2·6
Netherlands	10·2	4·8	2·2
Switzerland, largest	10·8	5·5	2·6
„ normal	9·8	4·9	2·6

All the bricks are parallelepiped in form, though some Roman bricks were triangular.

At the present time in all countries there is a general opinion that the volume of bricks should be between 130 and 59 cub. in.,

the length double the width, with an allowance of 0·12 to 0·50 in. for a joint. The width is seldom more than 5 in., so that a bricklayer may easily take the brick between his fingers when it is lying flat. Hence the length ought not to exceed 10 in. The thickness should not be more than 3 in., so that the drying does not take too long; nor less than 2 in. if the price of laying the bricks in building is not to be excessive. The normal German size, on the one hand, and the size proposed by the Pottery Union of France, on the other, may be taken as the two limits for the most convenient working. The standard size for English bricks, viz. $9 \times 4\frac{3}{8} \times 2\frac{5}{8}$ in., is a good average. Some builders, however, prefer bricks 3 in. thick instead of only $2\frac{5}{8}$ in.

Bricks were, at one time, made exclusively by hand, but the increased cost of labour and the enormous demand for bricks

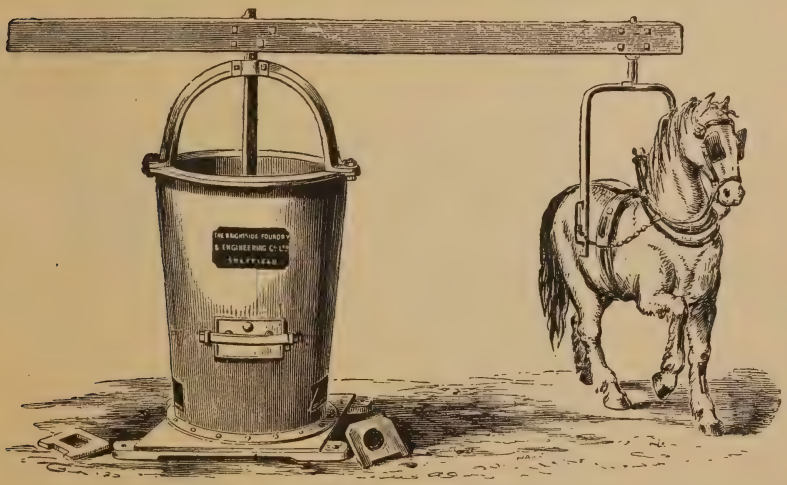


Fig. 176.—Horse-driven pug-mill.

during the last half century has resulted in many millions of bricks being made by machinery.

Moulding by hand is the oldest method of brickmaking, and is still the cheapest in some localities where the clay or brick-earth requires a minimum of preparation. In all other localities bricks are made by machinery. For successful hand-moulding the clay should be somewhat sandy—a marl or loam being better than a more plastic clay, which adheres too closely to the moulds.

The preparation of the clay or brick earth usually consists of a simple mixing (p. 94). Treading with the feet or by animals is less satisfactory than pugging, and is seldom used. As in "hand" brickfields there is usually no motive power, the mixers are worked by a rod fastened directly on to the vertical bar and rotated by hand or horse-power (Fig. 176). The output of these horse-driven mixers

varies from 26½ to 53 cub. ft. per hour, but this is very inefficient, and is better replaced by a portable engine.

The clay should be made of the required consistency by moistening it either in a heap or a pit (p. 92). If sand is to be added, it should be fed into the mouth of the mixer in suitable proportions.

The clay paste used for making bricks should be of such a consistency that it leaves the mould readily and yet the brick does not lose its shape because the paste is too moist.

The moulding is done on a table before which the moulder stands. A wooden brick-mould is shown in Fig. 74. Iron moulds or wooden ones strengthened by iron bands, may also be used. In some localities two moulds, fitting together, are employed ; in others, the mould, instead of being a simple frame, has a bottom to it.

To prevent the clay from adhering to it, the mould is first dipped in a bucket of water, and may afterwards be well dusted over with sand.

The moulder takes up a slightly larger quantity of the clay paste

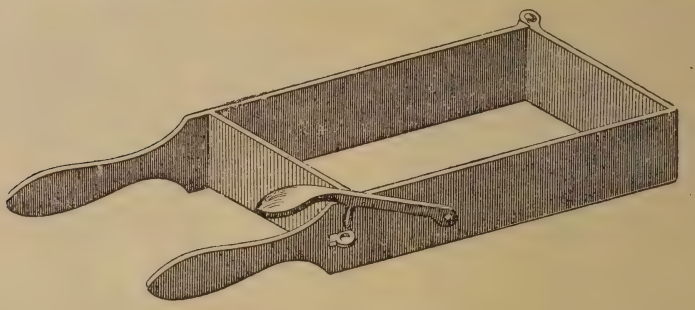


Fig. 177.—Mould which can be opened.

than is necessary, throws it sharply into the mould, and afterwards levels the upper surface with a scraper termed a *strike*. The mould is turned over in such a way as to set it on edge. It is then carried to the floor where it is turned over again, so that the face which was uppermost at first is placed on the ground. The slight shock given while putting the mould on the floor loosens the brick, so that it readily slides out of the mould when the latter is raised. In some localities, the mould instead of being carried, is emptied on to a little board or *pallet*, a second board is then laid on the brick, and the whole is taken to the floor, the brick being then held vertically between the boards and deposited by drawing them away. If the mould has a bottom to it, it is turned over, so as to discharge the brick on to the floor.

Moulders of different nationalities each have their special methods. They usually work in gangs composed of the moulder and one, two, or three assistants, who help to carry the bricks and take them out of the moulds. Under the most favourable circumstances a moulding

gang may make 600 to 700 bricks an hour, but there will be many defective ones, because to work at so high a speed a very soft body is used. The stiffer the body, the better the quality, but the lower the output. To make bricks of good appearance and of best quality, it is necessary to use a body of such a stiffness that it is not easy to take them out of the moulds.

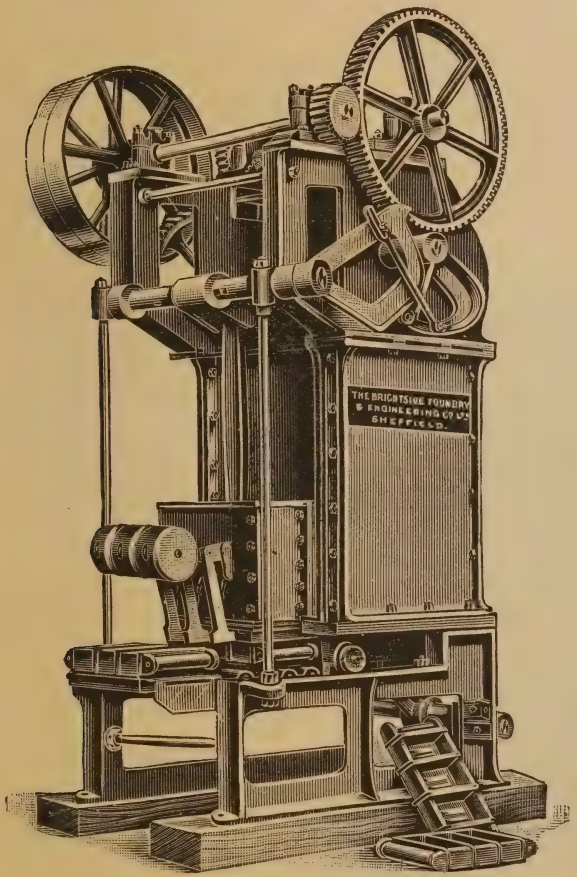


Fig. 178.—Machine for sand-stock bricks.

Moulds which can be taken to pieces (open moulds) are sometimes preferred, and may be constructed in various ways, the most usual type being that shown in Fig. 177. With such a mould, the quantity produced is reduced to 150 or 200 bricks an hour.

Moulding by Machinery.—In the first machines used for making bricks, hand-moulding was naturally imitated, the idea being to introduce an excess of body which was rather soft into a series of

moulds, and to compress it by passing these moulds under a rotary cylinder or under a vertical pugmill ; sometimes the bottom of the mould was movable, and by raising it the pressure was increased.

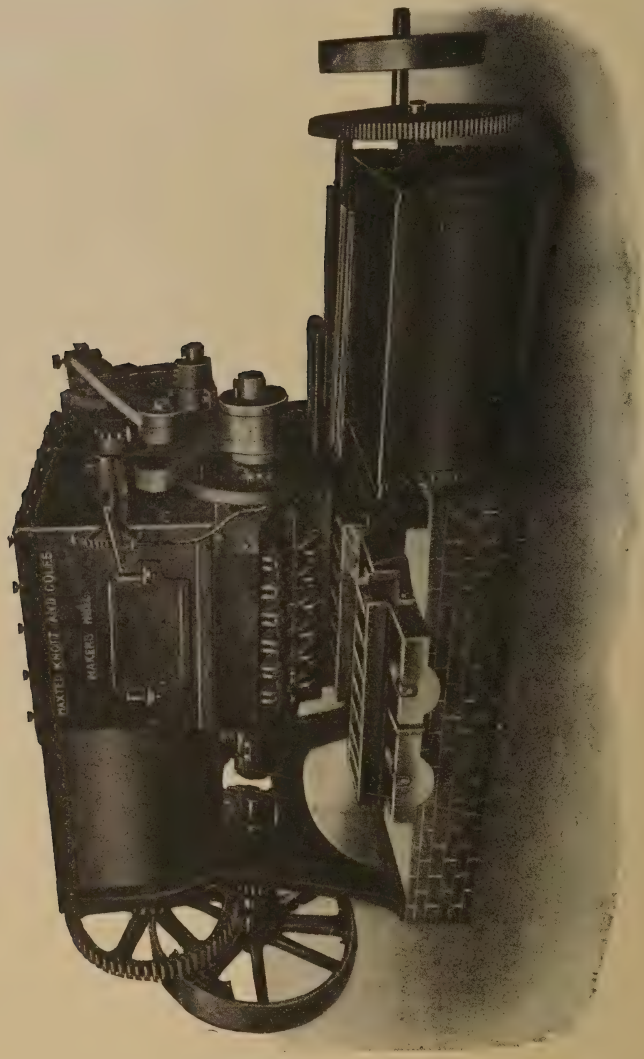


Fig. 179.—"Monarch" brick machine.

Fig. 178 represents one of these machines, including a vertical pug-mill ; in Fig. 179 a horizontal pug-mill is used. The output of these machines is 2500 to 3000 bricks an hour. The direct expenses of working are always higher if machines are used.

These machines are only used to a very limited extent where the demand is confined to bricks which appear to have been hand-moulded.

Where labour of the kind required is abundant and sufficiently cheap, moulding by hand is the best and the most economical method of working. It has the disadvantage of producing bricks which cannot be handled, and require considerable space for drying, shrink much, and being very porous, have little power of resistance. If, in making by machinery, a body as soft as that for hand-moulding is used, the same disadvantages are experinced, so that machine-moulding is useless if stiffer bodies cannot be made, so as to make bricks which can be handled more easily and dried more quickly.

Soft-mud machines are much used in the United States. They consist of six wooden moulds joined together and strengthened by iron facings, similar to those shown in Fig. 180 ; they are placed under the press, which fills them, compresses the body, and pushes them on to a board from which they are taken off, while a new group of moulds is put in their place.

At the present time the two chief methods for machine-moulding

Fig. 180.—Multiple mould.

plain bricks are : (1) Expression from half-soft or half-stiff bodies ; and (2) moulding in a press. Sometimes the bricks made, either by hand or by expression, are re-pressed to improve their appearance.

Manufacture by Expression.—When articles are made by expression, the stiffer body must necessarily be more plastic than for hand-moulding. In this process, which is often termed the *wire-cut process*, the paste is made by crushing the clay between rolls and then forcing it through a mouthpiece or die (p. 118) lubricated with oil or water, so as to form a column or bar of clay paste which corresponds in width and depth to the length and breadth of the brick ; it is afterwards cut in pieces the size desired for the bricks. Dies of this kind, called *cross cut*, make bricks which are smooth on all the visible surfaces, while the two large surfaces which receive the mortar are rougher by being cut with the metal wire. In some machines, the bar of clay corresponds to the breadth and thickness of the brick, the cutting then being done at intervals equal to the length of the bricks. With a large machine a greater breadth can be given to the bar of clay, and it can be cut as it comes out of the die by means of several wires stretched across, as shown in Fig. 181. The space between these wires is equal to the thickness of the brick,

the height of the die equal to the breadth of the brick, so that it is necessary to cut the parallel bars into pieces equal to the length of a brick. With this die, termed *longitudinal cut* or *end cut*, only the two long surfaces are smooth, the two ends—being cut by wires—are rough. Among the five classes of *propellers* used in pottery (p. 120), those with pistons are not used for making plain bricks, on account of their small delivery; they are used for coping blocks and special bricks.

For plain bricks, an arrangement of *propellers with blades*, forming a *pug-mill*, is generally used to form the column of clay. The propeller generally serves at the same time as an horizontal mixer, the hinder part of it being composed of movable and fixed paddles (p. 122); these act as a mixer, while the front part has a regular helix form (Fig. 67), and serves as a propeller.

The dimensions of these different parts, the inclination of the outlet, and the speed of rotation, must be adjusted to the stiffness

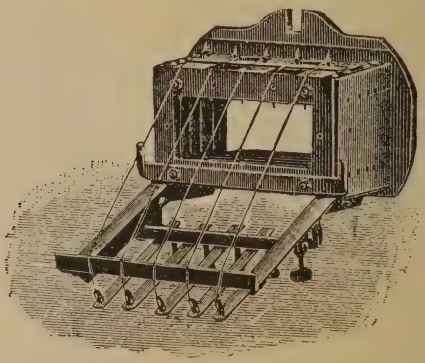


FIG. 181.—Die for plain bricks.

and plasticity of the body. The most suitable consistency is that which allows of five to ten rows of bricks to be piled up on coming out of the machine. If it is softer, it has the disadvantage of bricks moulded by hand, and if stiffer, the power expended becomes very considerable. The plasticity of the material should be sufficient for it to take a regular shape, without being torn when it comes out of the die; but a too plastic body should be avoided, as it has the same disadvantages as too stiff a paste, that is, an abnormal increase of power is required or the output is greatly reduced.

When the body contains no gravel or stones, it may be put direct into the pug-mill; in other cases, it must first be passed through a pair of rollers or otherwise crushed.

Fig. 182 shows a machine much used to work up the more difficult bodies. It has two sets of rollers, placed immediately over the pug-mill to crush the clay, and beneath them is a pug-mill in which the clay is mixed with as much water as is needed to form a

paste of the desired consistency. The product is shaped by the mouthpiece and received by the table, where it is cut into bricks by the wires shown. Some clays and shales require even more vigorous treatment, including one or more edge-runner mills. It is sometimes an advantage to dry the clay, crush it to powder, sieve it, and then mix it with water to form a paste which can be expressed through a mouthpiece as described ; stony clays can be best dealt with in this manner.

The output of a machine of the type described varies from 1000 to 4000 bricks an hour, using 10 to 30 horse-power.

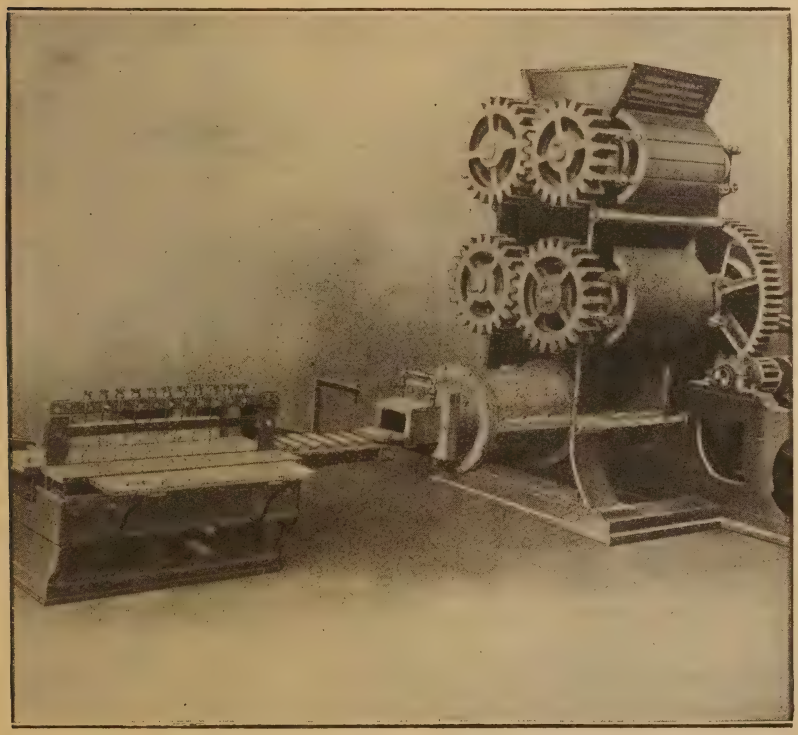


Fig. 182.—Brick machine for tough clays.

Fig. 183 represents a machine of the same kind, in which only one pair of rollers, placed directly over the pug-mill, is used. These machines produce 500 to 2000 bricks an hour for an expenditure of 4 to 20 horse-power.

A large number of machine manufacturers make similar machines differing from each other chiefly in their structural details, thus, some machines, instead of having only one die plate, have two placed side by side and inclined to the axis of the screw. This arrangement—by making the passage of the body more difficult—

greatly increases the power expended, and it is not to be recommended.

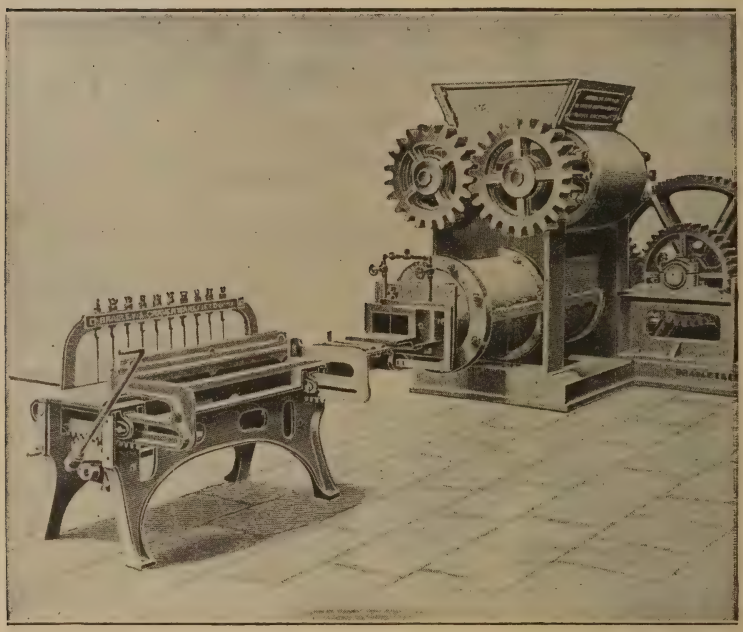


FIG. 183.—Brick machine.

In another machine constructed by Messrs. Chambers Brothers & Co., of Philadelphia, shown in Fig. 184, the barrel contains a set

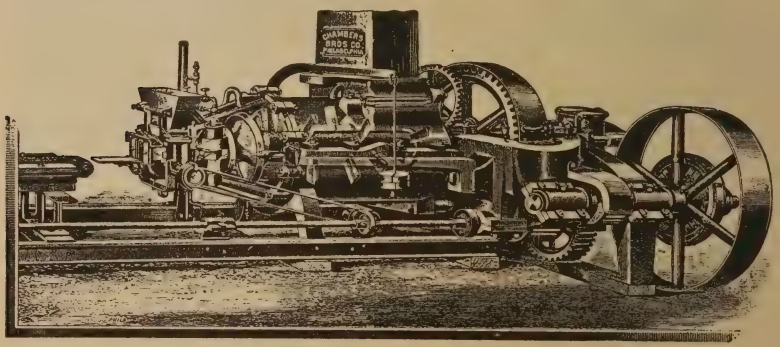


FIG. 184.—Chambers' brick machine.

of mixing blades and also a propelling screw. The bar of clay has for its width and height the width and thickness of a brick. The

walls of the die are heated with steam. A hopper, placed above the die, contains sand, which is dusted on to the bar of clay by a separate mechanism. A safety valve, kept in place by a counter-weight, prevents the pressure on the clay from exceeding a certain limit. The output of this machine may reach 4000 bricks an hour, it being a characteristic of American machines to be larger and to produce much larger outputs than similar machines in other countries.

All these machines require a *cutting table* (p. 123), such as those shown in Figs. 182 and 183. In these, the wire, after cutting the clay, tends to tear the edges; this may be remedied by using movable frames which cut in a downward direction. The cutting table limits the output of the machines to 2500 or 3000 bricks an hour.

Automatic cutters have been tried, but for the most part without any satisfactory result, the machine invented by Chambers Brothers

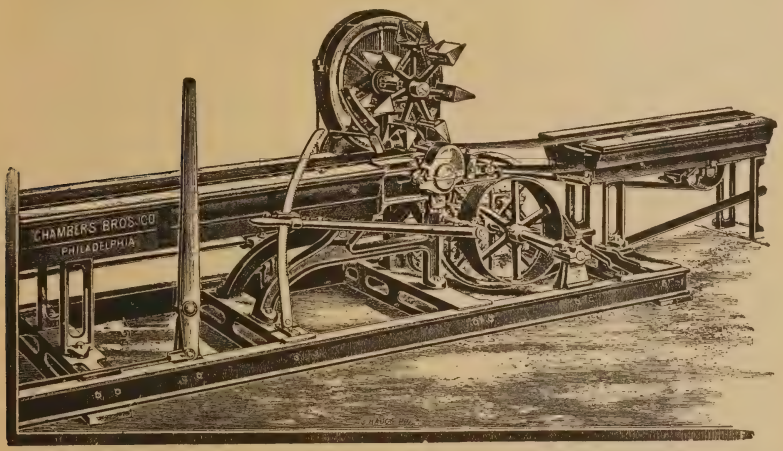


Fig. 185.—Chambers' cutting appliance.

& Co., notwithstanding its complication, being one of the best solutions of the problem. As shown in Fig. 185, which is a continuation of Fig. 184, the bar of clay is received on an endless band which moves with a speed equal to that of the body and is regulated by a sloping lever. Above this slowly moving band a vertical wheel turns with a speed corresponding to that of the band, and is furnished with seven arms carrying wires, which, by their circular movement, cut off the bricks to the desired length. The bricks, when thus cut off, are pushed on to a second endless band, moving more rapidly, so that they are separated from one another, and can afterwards be taken up separately by a series of workmen, who stand by the table on which this second endless band runs. By this process 200 bricks a minute can be cut.

The *propellers with two screws* mentioned on page 123 are often

used as preliminary mixers in the manufacture of bricks. They are not very good for compressing the paste, but being excellent mixers are used advantageously, prior to the paste entering the pug-mill. These machines are always surmounted by a pair of rollers, to crush the clay. Their output varies, according to size, from 160 to 4000 bricks an hour for an expenditure of 3 to 25 horse-power.

Propellers with cylinders, though more logical than the preceding ones, do not give good results in the manufacture of plain bricks except when using soft bodies. It can easily be understood that the passing from a large and very thin section, like that which exists between the cylinder propellers, to a section that is almost square as in the die for plain bricks, will only work when the body is plastic and not very stiff.

Manufacture with a press involves the use of a dry, semi-dry, or stiff-plastic body, that is to say, the raw materials must be in a state

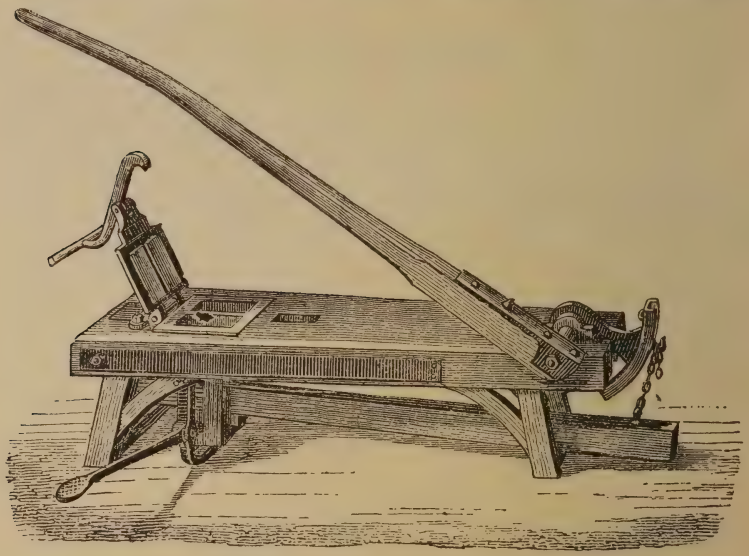


FIG. 186.—Hand-power lever-press (old type).

of a more or less damp dust, and if pasty they must be so stiff that they do not cohere to the mould after pressing. The bricks thus obtained have a granular appearance, and need more burning to replace, by vitrification, the absence of cohesion possessed by plastic bricks. This process is used for rocky or sandy materials, the pressure used partly making up for the lack of plasticity ; its chief advantage being the absence of capital expenditure on dryers and the lesser handling, which tend to reduce the cost of manufacture ; this is, to some extent, counterbalanced by the much greater power needed and the greater fuel consumption in the kiln. The latter is

frequently off-set by carbonaceous material in the clay or shale used. The body is usually a sandy clay or shale, and is simply reduced to a homogeneous powder which is given as much dampness as corresponds to the pressure which can be saved. In most cases, the materials must be very thoroughly mixed, or the irregular distribution of the moisture will cause weak bricks to be produced.

The mould or die-box (p. 136) in the press must first be filled with the material, which is then subjected to pressure. As there is a very large number of presses on very different systems, a complete description of them would only have a slight interest ; the following are some of the chief types :—

For small quantities, a shock-pressure may be used (Figs. 89 and

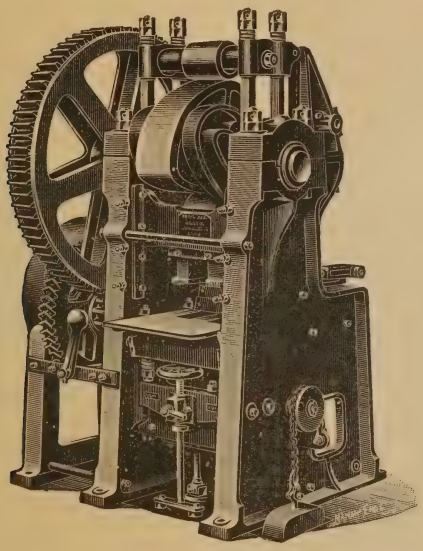


Fig. 187.—Nuneaton press.

186). In the press shown in Fig. 186, which is much used in small brickfields, the two moulds, which are usually of bronze, have movable bottoms and a cover with hinges, which is closed by means of a hook, after the moulds have been filled by hand. By using a double lever, a pressure is exerted on the bottom, then the cover is opened, and by means of a pedal the bottom is raised up so that the bricks may easily be taken out. With such a press, a moulder with two helpers can make about 300 bricks an hour.

For larger quantities and for bricks of a better quality, power-driven presses with a continuous motion are used. The press constructed by MM. Boulet et Cie, shown in Fig. 93, is an example of this kind of machine ; it can produce 800 to 1000 bricks an hour, with an expenditure of about 8 horse-power. In the English machine shown in Fig. 187, the two moulds are filled with clay dust, the

plunger is lowered rapidly, then released to allow the air to escape ; it then gives a second greater and more prolonged pressure, after which the bottoms of the moulds are raised and exert a third pressure. Later, the bricks are taken out of the moulds as in the preceding presses by raising the bottom of the latter. A screw placed in front of the press allows the thickness of the brick and the pressure to be regulated. The moulds and pipes may be heated by steam to prevent the clay from sticking to them.

Hydraulic presses are seldom used for making plain bricks because of their small output.

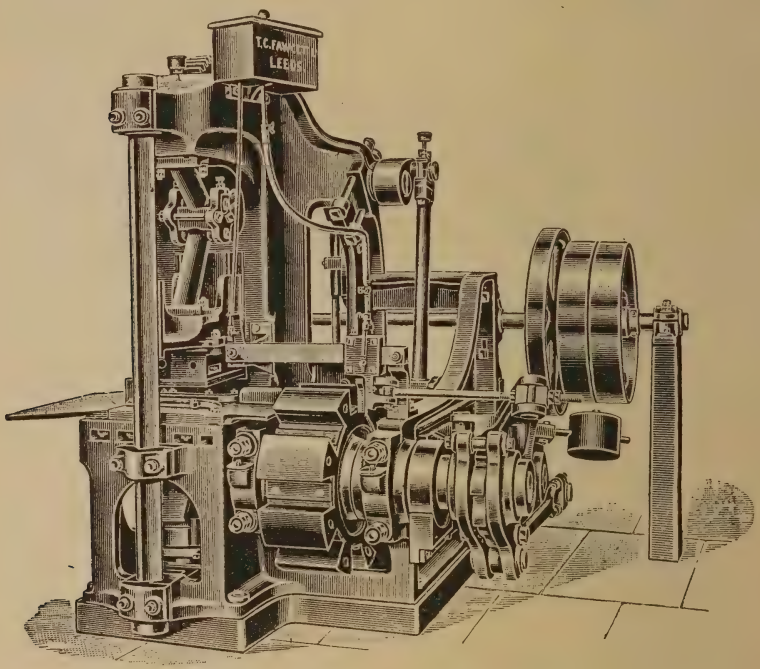


Fig. 188.—Fawcett's brick machine.

By using clays in a stiff-plastic state, less powerful machines may be employed with good results ; this has led to the introduction and use of a series of different presses in which the stiff paste is roughly shaped and is then passed into a press. Thus, in Fig. 188, the clay from a small pug-mill with a strong propelling action is forced into a mould, on the circumference of a drum which carries eight moulds. This drum makes an eighth turn each time and then stops. In the first position each mould is filled with the clay ; in the second, it is in an intermediate position ; and in the third the rough brick is pushed out of the mould on to the table of the repress, and is automatically lubricated. In the press, the rough brick is

accurately shaped and is delivered on to a table from which it is removed by an attendant. In *duplex* machines of this type, two bricks are made simultaneously. The yield of this machine is 1200 bricks an hour for the single type, and 2400 bricks per hour for the duplex type. If the clay is particularly easy to work, a slightly higher output may be obtained.

Many other types of press not mentioned herein are now at work and are regarded as standard machines. The publishers of this treatise will be pleased to supply further information on request, and to suggest other books in which these machines are described.

Repressing.—Bricks may be manufactured in two separate operations. In the first, the bricks are fashioned of plastic body by one of the methods already described; then, when they have been partially dried and are of a leathery consistency, they are pressed so as to give them a true parallelepipedal form, with hollows ("frogs") on the two large faces. The object of these frogs is to force the body to push towards the edge when in the press, and to diminish the thickness of the joints by leaving a place for the mortar.

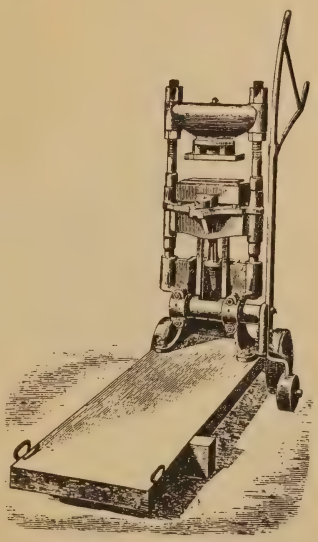


Fig. 189.—Hand-lever press.

Represses are similar to ordinary presses, and may be worked either by a lever or by other mechanical pressure. Generally, the represses worked by hand have a lever; they are portable, so that they may be moved about the drying ground or dryer and thus avoid unnecessary carriage of the bricks. Fig. 189 shows the ordinary type of lever repress. The brick is placed on the bottom of the die by an assistant, then the workman standing on the platform shown in front seizes the lever and throws it violently down, leaning on it to make it bear the weight of his body. By this movement the bottom of the mould is lifted, the brick is forced into the die, and the plunger presses on to the brick. The lever is raised after the stroke, the workman then takes the brick out of the mould, and it is carried away by the labourer and replaced by more clay. In this way 350 to 400 bricks an hour can be repressed.

Another repress is shown in Fig. 190; it carries three moulds on a turn-table, which allows of one brick being taken out and another being ready for lubricating and for putting in the die. Fig. 191 shows a third arrangement, in which the stroke is produced by the great power accumulated in a very heavy flywheel.

If the goods, though of a suitable consistency for repressing, are

not sufficiently plastic for pressing by hand, they may be treated to a much greater pressure in a power-driven press, in which they

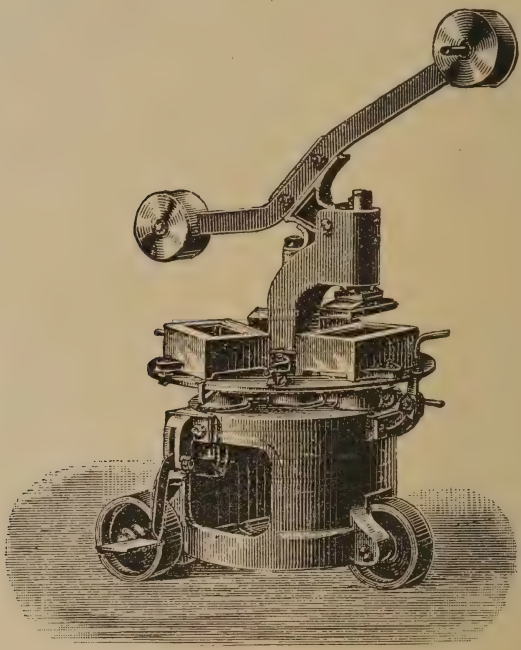


FIG. 190.—Portable repress (French type).

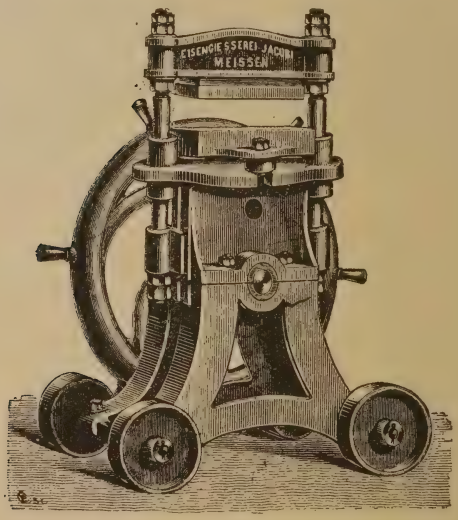


FIG. 191.—Portable repress (German type).

are prevented from sticking to the mould by previously lubricating the latter with vegetable or mineral oils diluted with water or with an emulsion of soap.

When the clay contains lime the lubricant may become saponified, forming calcareous salts which are destroyed in burning, but which leave a residue of lime on the surfaces of the brick, and thus produce whitish blotches which it is impossible to remove. To avoid this

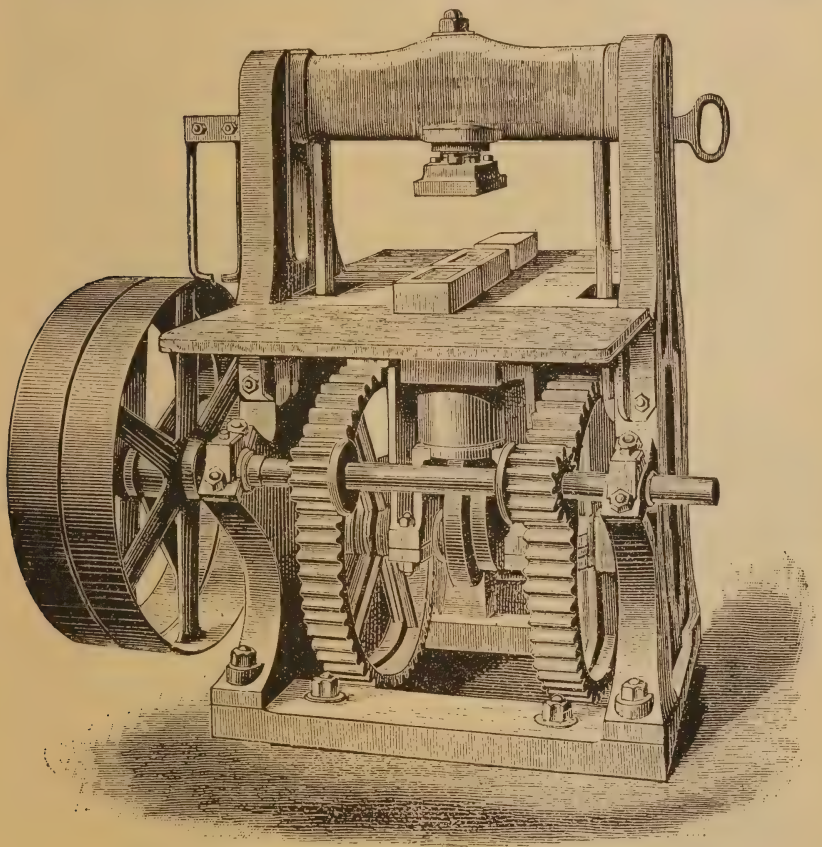


Fig. 192.—Clayton's repress.

inconvenience, mineral oils which do not contain fatty acids must be used.

When labour is cheap and fuel dear, the larger output of a power-driven machine, which is necessarily a fixed one, does not often make up for the increased expense caused by carrying the bricks to and from the press. Repressing machines are of many kinds ; the following are typical examples :—

The repress (Fig. 192) constructed by Clayton resembles the one

just described. Two eccentric wheels mounted on the drying shaft move the bottom of the die and the plunger. On the other hand, in the machine (Fig. 193) supplied by Pinette pressure is applied horizontally. The bricks are put on to a travelling slide in front of the machine, which carries them opposite the die, where a plunger pushes them in and presses them. The bottom of the die is pushed up in its turn, and puts the repressed brick back on the slide, which carries the finished brick to the other side, whence it is removed. This machine is said to repress 1000 bricks an hour. Fig. 194 shows a repress constructed by Frey, in which the bricks are placed on an endless band which carries them into the machine, where they are placed laterally by a cam, and pass out on the other side on to the

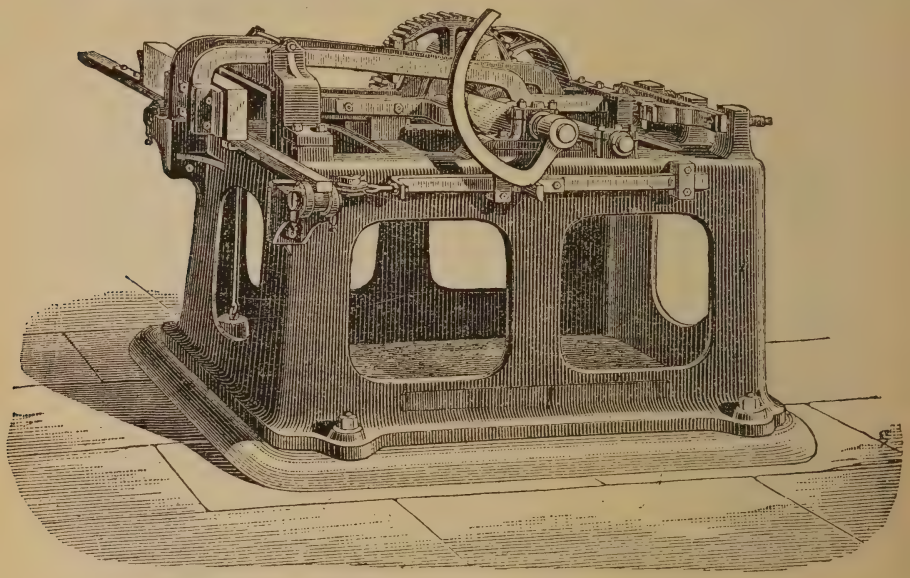


Fig. 193.—Pinette's repress.

same endless band. Two rollers automatically lubricate the bricks as they enter. The output is a little larger than that of the preceding machine.

Most of the power-driven represses used in Great Britain are of entirely different appearance though similar in principle; two of them are shown in Figs. 187 and 188, but there are many others.

Repressing improves the appearance of bricks but not their quality, because under the influence of pressure the particles of the body are displaced laterally, and are to a certain extent pressed together; but as their plasticity is very low, they blend very badly together, and cracks are left in the goods which lessen their resistance to crushing.

Drying bricks is a difficult operation, on account of the large

quantity of water which has to be evaporated under such conditions that the bricks are not cracked. Thus, bricks, when moulded, may

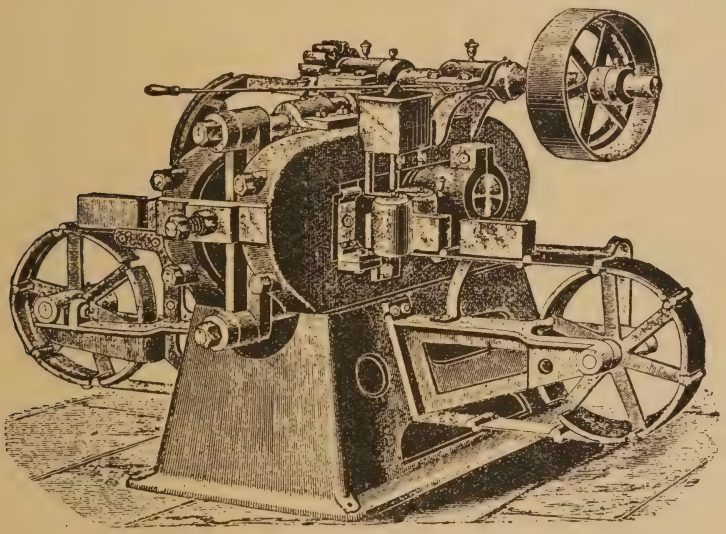
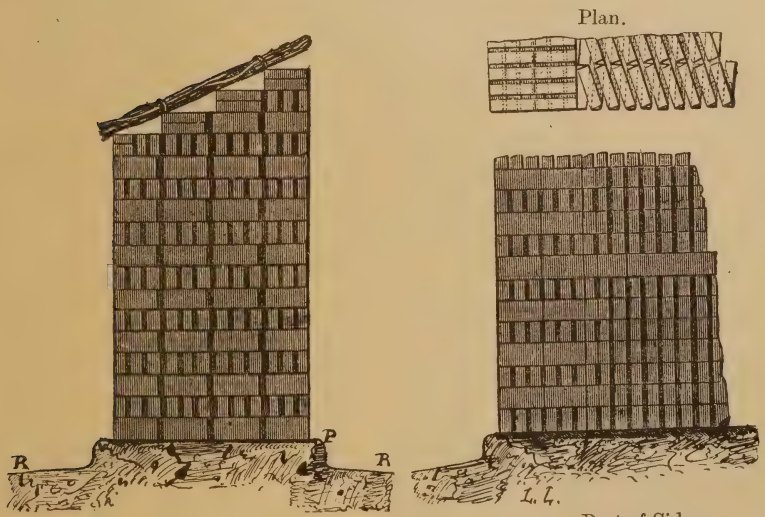


Fig. 194.—Frey's repress.



End View. Part of Side.

Fig. 195.—Hacks (French method).

contain about 25 per cent of water if made by hand, 15 to 20 per cent when made by the wire-cut process, and 10 to 15 per cent when made of a stiff-plastic paste, but only 5 to 10 per cent when a

dry body is pressed. If the proportion of water present is only 14¼ per cent, no less than 10 tons of water must be removed in drying a chamber containing 20,000 bricks of normal English size.

Bricks are dried by one of four processes : (1) Drying in the open air ; (2) drying on shelves which are either isolated or grouped together in a building ; (3) drying in ventilated drying sheds, using the waste heat of the kilns ; (4) drying in warmed and ventilated drying sheds.

Drying in the open air is only used when the bricks are moulded by hand. In France, as the bricks come from the mould they are laid flat, side by side, on a large surface of prepared ground, slightly sloping so that the water drains off naturally. When they have hardened sufficiently they are spread out, then after drying again for a time, they are piled up into a heap—in *hacks*. In England the bricks are so arranged that the hacks are formed at first and not at a later stage as described. These hacks are placed on the higher parts of the ground, the lowest row often being of burned bricks, to avoid damp. When there is any fear of rain, the hacks are covered with straw matting, planks, or other light movable coverings. Sometimes one side of them is covered as well, to prevent the rain being blown on them by the wind. In these piles or hacks the bricks are left until fully dried.

Drying on shelves is done either in little separate sheds, or in sheds that contain several rows of stages, or even in buildings con-

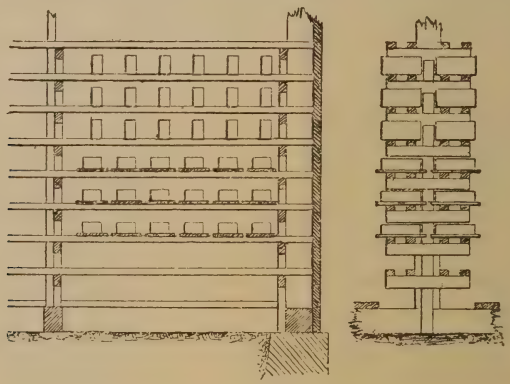


Fig. 196.—Drying racks.

structed over the kilns. Figs. 102, 104, and 196 show the different arrangements in general use. When the bricks are made of soft paste, they should be put on *pallet* boards, but if the body is stiff plastic, or semi-dry, the bricks are at once placed on two strips, forming a shelf and fixed to the upright of the stages. Fig. 196 shows both these arrangements.

Bricks are sometimes put on boards, about 4 to 5 ft. long, directly they are made, and these boards are carried to the drying racks,

where they take the place of the strips in Fig. 196. In some cases, movable shelves are formed of planks with "legs" at their ends (known as *stools*), which may be piled up, as shown in Fig. 197, without any other supports being needed.

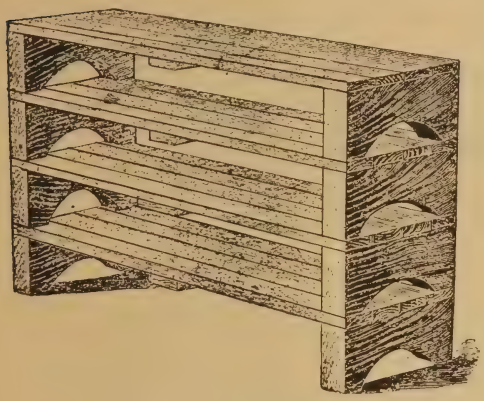


FIG. 197.—Drying stools.

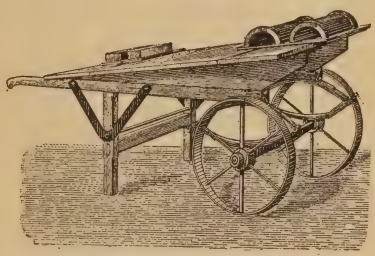


FIG. 198.—Off-bearing barrow.

Wheelbarrows are preferred to other vehicles for carrying the bricks from one place to another, because they can easily be moved about between the rows of the shelves. Those used for carrying green bricks are known as *off-bearing* barrows; they are large and

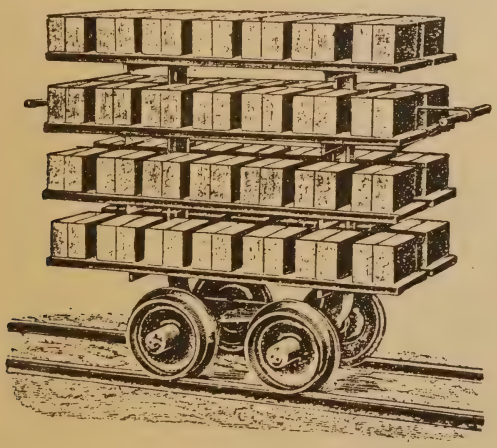


FIG. 199.—Brick wagon or car.

flat in form, as shown in Fig. 198, and should have good springs. For transporting dry bricks, simple flat wheelbarrows, with backs (known as *crowding barrows*), are used. When it is necessary to raise the bricks on to the shelves the barrows may be pushed up

inclined planes, or they may be raised by a lift. Sometimes, a special (Keller) car is used by means of which all the bricks can be raised and placed on shelves by a single movement.

Other wagons are only used in larger works, because they need a considerable amount of rails to be laid if they are to be carried along between the stages. For green bricks, the wagons shown in

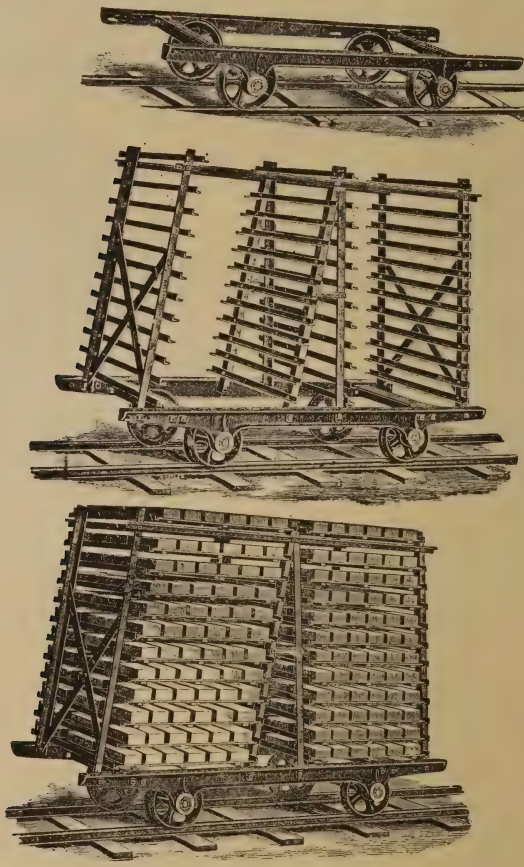


Fig. 200.—Brick wagons.

Figs. 199 and 200 are used, and for dry bricks wagons of the usual flat shape. In some cases, wagons suspended from an overhead railway are used ; this method, when the arrangement of the works permits of it, is often more practicable than the preceding one.

When the making is done in a building which contains the drying sheds, elevators may be arranged by the side of the machines, and the bricks, being placed in them, can at once be taken to the

different floors, put on wheelbarrows, and then on the shelves; Fig. 201 represents an elevator of this kind.

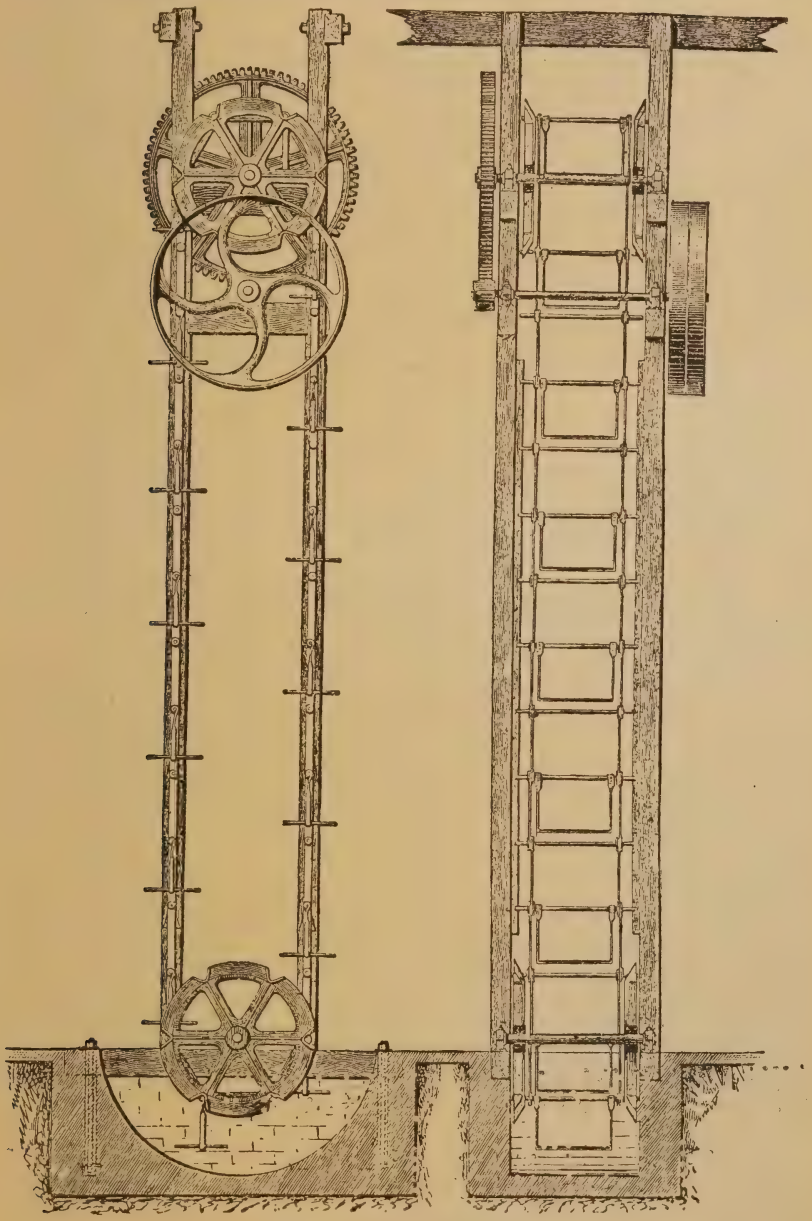


FIG. 201.—Brick elevator.

The length of time needed for drying bricks on the shelves depends on the arrangement of them and on the weather. When dried in hacks in the open air, the drying time varies from two to five weeks in favourable seasons. It can be reduced, when shelves are used, and under better conditions, to ten or even eight days. The speed of drying without artificial heat at a height of 10 ft. is double that on the ground itself, and is trebled at the height of 20 ft. Drying without artificial heat is only feasible in times when there is no risk of frost, and when the atmosphere is not too moist, but by using artificial heat (e.g. by arranging drying sheds over the kilns, as shown in Fig. 104) the bricks can be dried at any season if the building is in good order. The length of drying, nevertheless, depends largely on the season, even with the best of such arrangements, and is double, or even treble, in winter what it is in summer.

The drying can be noticeably improved by arranging fans in suitable places, which may be used in calm weather, when the natural draught is insufficient.

Ventilated drying sheds, using waste heat from the kilns, may also be employed (Fig. 105). The kilns may be of either the single or continuous type, and the ventilation is effected by chimneys or fans. Several arrangements have been proposed.

The heat necessary for evaporating 1 kilogramme of water contained in the body is (p. 154)—

$$C = \frac{1000(T - \theta)c}{E(T - t)}$$

with the condition—

$$E(T - t) \leqslant P - p.$$

If the outside temperature (θ) is equal to 0° and T = 20° C., the heat expended is at a minimum when $t = 11°$, in which case C = 1360 Calories (p. 154). This number must be increased by 50 to 100 per cent, according to the installation, and becomes, under the most favourable conditions, equal to 2000 Calories.

If, on the other hand, a body has 10 per cent of water to be removed by drying, 1 kilogramme of burned brick will contain 150 grammes in all, thus needing 300 Calories. But the quantity of heat a continuous kiln can furnish while burning bricks will scarcely exceed more than 200 Calories per kilogramme of burned clay, so that it is impossible to dry bricks solely by the waste heat of a continuous kiln, though this is often the only heat available in brickfields which are worked economically. It is this fact which has caused heated and ventilated drying-sheds to be used (Figs. 108 to 113). When the shelves are fixed, the bricks are placed as already described ; otherwise, wagons are used which carry movable shelves on fixed iron supports, as shown in Fig. 202. These wagons, loaded with bricks, are then put in the drying-sheds.

Fig. 203 shows a dryer, type (*c*) (p. 164, Fig. 109), and consists of a series of separate tunnels, with fireplaces at one end, flues

or steam-pipes beneath the floor, and a chimney at the other end. Each tunnel is filled with bricks on cars, which remain in the tunnel until dry.

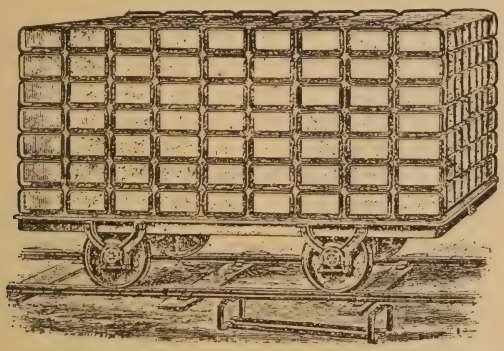


Fig. 202.—Brick wagon.

Fig. 204 (*a*) shows a different type, in which the goods are moved in the same direction as the air, the later being heated progressively by a subterranean set of pipes containing steam. It is known as

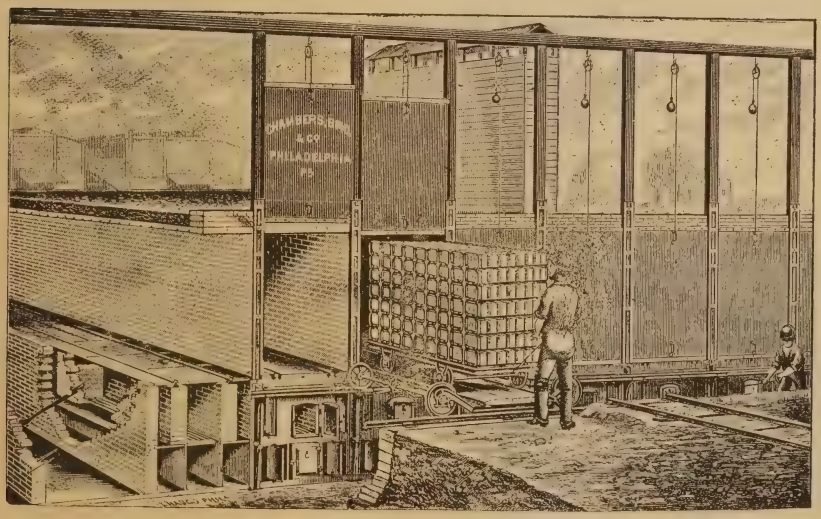


Fig. 203.—Tunnel dryer.

the Wolff dryer. A superior, but much more costly, dryer is shown in Fig. 204 (*b*), a plan of which is shown in Fig. 113.

In order to calculate the dimensions for drying-sheds and the number of wagons, the time needed for drying must be known or

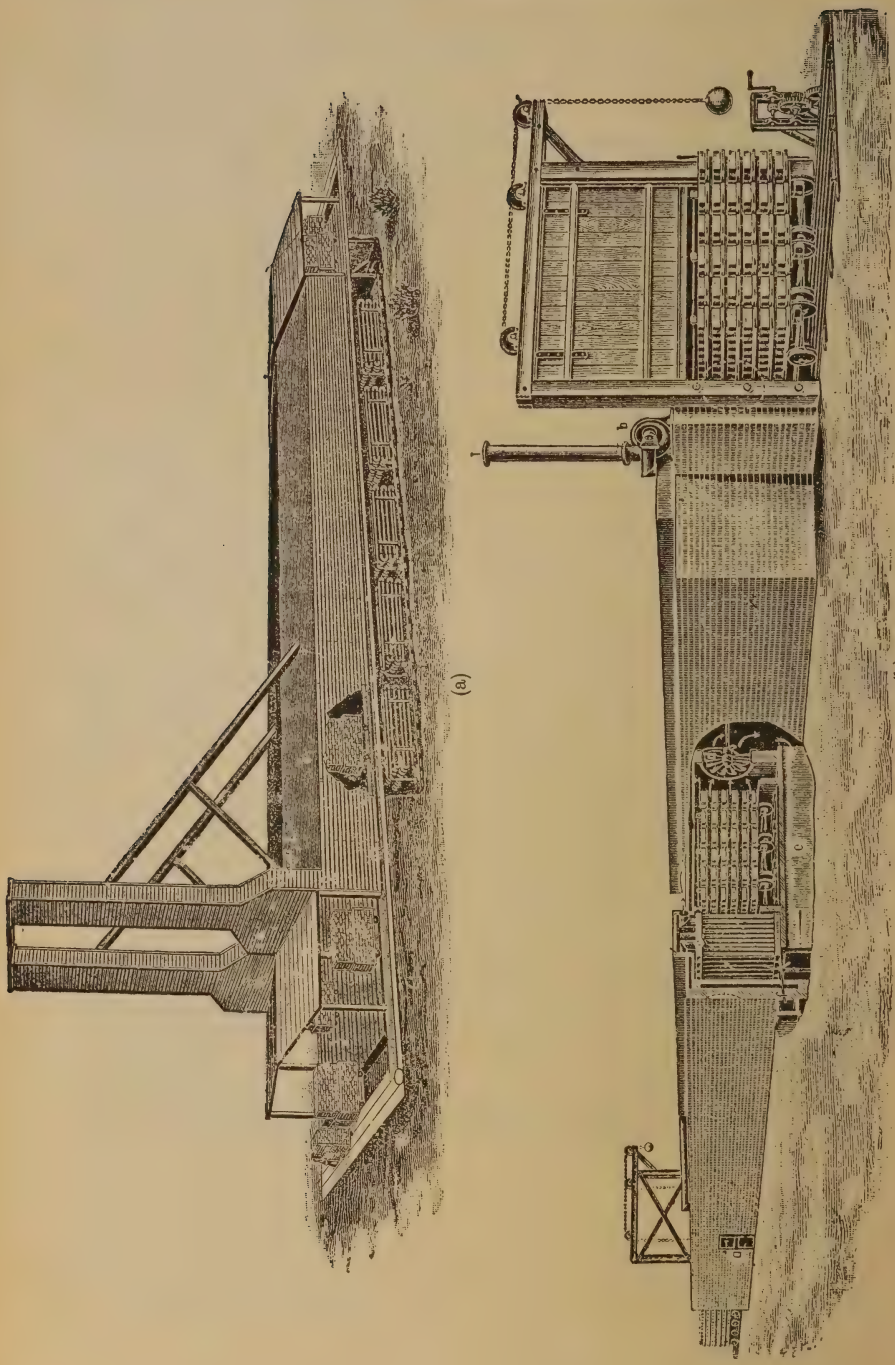


FIG. 204.—Tunnel dryer : (a) Wolff's, (b) Moeller & Pfeiffer's.

estimated. Under favourable conditions this time can be reduced to twenty or twenty-four hours, but it is often much longer.

The information given in Chapter VI allows various dryers to be compared and their fuel consumption estimated.

Heated drying-sheds are suitable for countries with a cold or damp climate, as in Great Britain. It seems hardly likely under present conditions of the brick industry that it would be advantageous to use them in countries where, as in France, bricks can be dried in winter on shelves suitably arranged above a continuous kiln.

Burning.—Common bricks are sometimes burned in open kilns, or *clamps*. This process is usually associated with moulding by

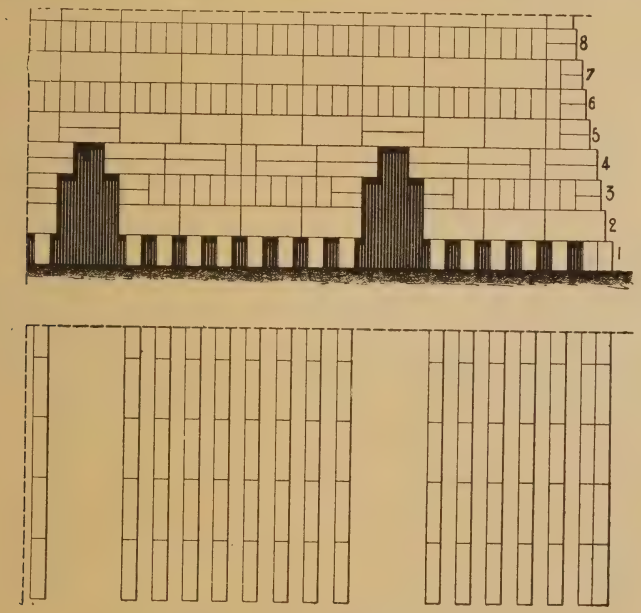


Fig. 205.—Section and plan of clamp.

hand, and as it requires men who have been specially trained, and the results are very uncertain, it is gradually being abandoned ; it may be described quite briefly. There are several methods of building clamps, according as the clay used for the bricks is or is not mixed with fuel before being shaped. The following method is the one commonly used in France and Belgium ;—

The site selected should be away from water and close to where the bricks are dried. A first layer of burned bricks is made as a square foundation (Fig. 205), measuring 11 to 16 yd. on each side. On this is laid a second layer of burned bricks placed across the first ones, and about $\frac{5}{8}$ in. apart. A third layer is made of bricks

laid edgeways, but with a space of $\frac{3}{4}$ to $1\frac{1}{8}$ in. between them. In arranging these bricks, cross-channels should be formed, as shown, to contain some of the fuel. When the three courses are completed, these cross-channels are filled with wood and shavings, then the fourth layer, composed of two courses of bricks laid flat and separated from one another as in the preceding course, is laid. At the fifth layer, the channels are covered over with flat bricks, and others placed edgeways at intervals like those already mentioned. The sixth layer is composed of bricks at right angles to those in the fifth, then the seventh like the fifth, the eighth like the sixth, and so on. The bricks at the edges of the clamp are closer together, and placed in such a way as to give a slight batter or slops to the outside of the clamp, which is afterwards covered with a layer of clay paste.

Between the sixth and seventh layers, coal or cinder-dust is spread evenly, and the same is done every three succeeding layers. The first seven or nine layers are of burned bricks, as they form the foot of the kiln, the others are green bricks. When the foot is finished—which will take a gang of ten to fifteen men a whole day—in the evening the wood put in the channels is lighted, and the fire is fed with faggots, blocks of wood and coal. The next day the setting is continued so as to put on three or four layers.

When the fire has well caught the first layer of coal, which can be told by the smoke, which ought to come evenly out of the whole surface of the clamp, the speed of the combustion is regulated by lessening the size of the openings which let the air in. Each day the setting ought to follow the process of combustion, which has a tendency to become quicker, so that towards the end of the burning as many as four to six layers are put on. The men usually stop when the kiln is about 8 ft. high, a cover or platting of one or two courses of bricks laid close together being then laid.

In England, a different method is used, the greater part of the fuel (in the form of cinder dust and known as *soil*) being mixed with the brick-earth. The remainder of the fuel (coke or cinder breeze) is then laid between some of the courses of bricks as described above. In this country, also, part of the clamp is built to the full height before lighting it, and the length is increased, day by day, until the whole of the available space is occupied.

With such a primitive method of burning it is natural that mistakes should be frequent. If the fuel is not spread evenly, the entrance for the air is lessened on one side where it is too thick, and any "chimneys" that may occur are stopped up from above by putting fuel into them. In the same way, the fire is quickened in the parts where it is too slow, by unstopping the air entrances. As the centre is necessarily more burned than the edges, it sinks more, and the difference in level is put right by placing a layer in which the bricks are edgeways in the centre, and sloping or flat down at the edges. But the most serious accident that can happen is rain, from which it is difficult to protect a clamp, even with

movable coverings. Hence burning in the open can only be done in the summer, and the results are always speculative.

A clamp may contain 200,000 to 1,000,000 bricks ; those most used contain about 500,000, of which about a sixth are waste or under-burned. The consumption of fuel varies from 63 to 181 lb. of coal per 1000 bricks, according to the quality of the coal or other fuel and to the size of the clamp.

Burning in the open is sued in the North of France, in Belgium, and in England, when the body is sandy. Its chief value is for small temporary brickfields, formed near to and in view of a particular building site, but it is also regarded as essential for " London stocks."

For small works in the Colonies, *intermittent kilns with ascending flames* of the type shown in Fig. 143 may be used, the heating being either with coal, wood, grass, straw, or any other fuel.

Besides the two methods just described, bricks are burned in continuous kilns ; only in very small brickfields created for local needs is use made of semi-continuous kilns.

Kilns with continuous firing have already been described (p. 225), and instead of the primitive round or oval form a rectangular form (Fig. 153) is used. Fig. 206 represents a kiln of this kind specially intended for burning bricks. Each of the two parallel galleries is divided into six, seven, or eight compartments, each having a door for filling, a damper and an arch making a projection in the walls of the burning gallery (" drop-arch ") against which the dampers are arranged. These dampers were formerly of iron plates in two or three pieces, to allow of their being put through the doors ; now they are made of paper fastened with mortar to the arch. When they need to be removed, the lower part of them is simply torn away, so as to let the gaseous current pass, the paper being destroyed during the burning.

The paper is bought in rolls about 40 to 56 in. wide ; it is cut and pasted in such a way as to be identical in shape with the opening between the chambers.

The kiln is heated with coal, lignite or turf, the fuel being put in through a series of small openings formed in the crown about 40 in. apart and closed by cast-iron covers. The setting is arranged as shown in Fig. 128.

With a normal working, the fire advances 10 to 24 ft. in twenty-four hours, but J. Bührer has obtained much greater rates of travel—up to 96 ft. per twenty-four hours—with kilns which are exceptionally long and narrow. With ordinary continuous kilns the chambers should not be too large, and with a " one chamber per day " output of more than 25,000 to 30,000 it is sometimes better to employ two distinct kilns.

The construction of the kiln shown in Fig. 206 may be varied in several ways :—

(1) The chimney may be quite away from the kiln, and either at one end or at one side (Fig. 153), though the position shown in Fig. 206 gives the best draught.

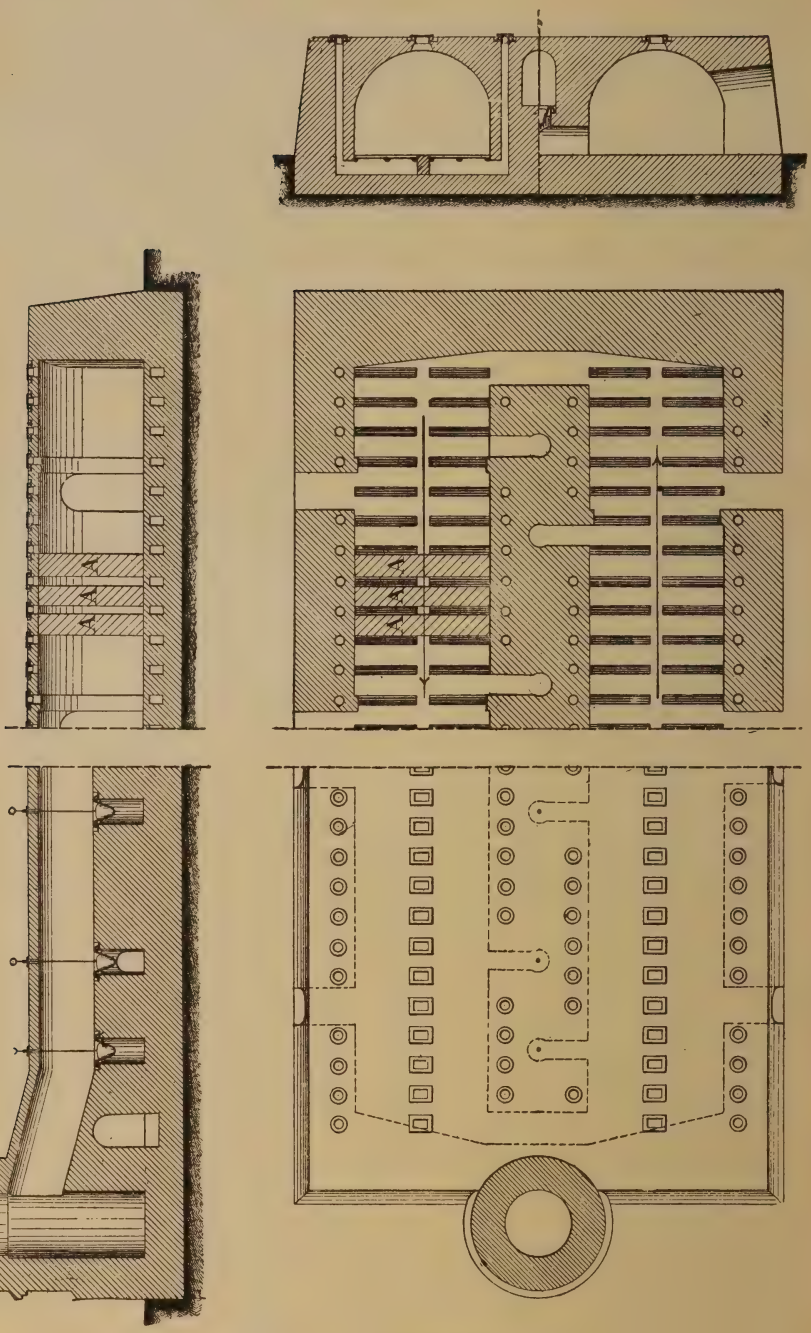


FIG. 206.—Continuous kiln.

(2) The flues for carrying off the gases, instead of being placed laterally in the central wall, may be built in the outer wall or under the floor, though these arrangements, which seem theoretically better, are of no practical advantage in distributing the heat uniformly, and are more complicated in construction; their chief advantages lie in the greater accessibility of the dampers and in the ease with which they can be repaired.

(3) The gases may also be carried off through the openings for supplying the fuel by making these feed-holes communicate with the smoke flue by means of movable sheet-iron pipes which are moved to another set of feed-holes as the fire advances. Fig. 207 shows

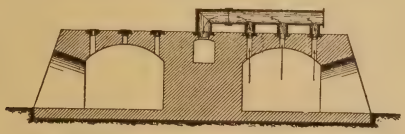


Fig. 207.—Movable flue on kiln.

this arrangement in section (Siehmon & Rost); it is simple in construction, and when the goods are damp removes the steam better and prevents it from accumulating under the crown of the kiln. On the other hand, the moving of the pipes is a much longer operation than the simple raising of a valve. It is generally preferable to carry off the hot gases through special lower flues, and when the raw goods are very damp, to carry off the steam by means of upper pipes as suggested.

(4) The warming of the freshly placed bricks sometimes needs special arrangements, and small movable fireplaces, heated with coke, are fitted to the chamber that is to be warmed, a large quantity

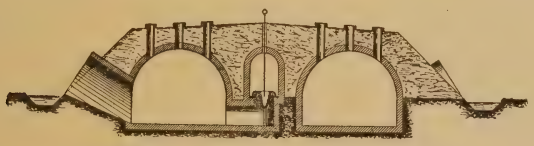


Fig. 208.—Temporary continuous kiln.

of air being allowed to enter at a low temperature rather than a small quantity of very hot gas. These fireplaces are placed in (i) special openings in the doorways; (ii) in the outside walls; or (iii) in the feed-holes on top of the kiln. The warm air from the chambers which are cooling may be carried through a special system of flues into a chamber just starting, but this does not give all the heat needed for very damp goods, and must be supplemented by heat from some other source.

(5) For temporary work, the construction of the kiln may be simplified by putting part of it in the ground, and replacing the greater part of the masonry by embankments of earth, as in Fig. 208.

Owing to the low cost of this construction and the much smaller proportion of waste bricks produced, burning in this kiln, including depreciation charges, is cheaper than in clamp or open kilns when the total number of bricks to be made is 2,000,000.

The kiln shown in Fig. 206 is intended for coal or lignite. Wood can also be used, but for heating with small wood, faggots, straw, etc., the kiln shown in Fig. 156 should be preferred. The average consumption of fuel is from 77 to 110 lb. of coal of medium quality per ton of burned bricks (or 3 to 4 cwt. per 1000 bricks), according to the temperature required and the nature of the clay or body. The much lower fuel consumption sometimes mentioned is usually due to combustible matter in the clay or body, which naturally (if not in excess or in some objectionable form) reduces the fuel consumption. This explains why some shales require only $\frac{1}{2}$ cwt. of fuel per 1000 bricks.

The thermic yield of a continuous kiln for burning bricks can be calculated as follows :—

Heat produced by the fuel . .	100	Heat theoretically required .	90
Heat collected from cooling goods	40	Heat lost by heating the walls .	20
		Heat lost by radiation . .	25
		Heat lost by the chimney . .	5
	140		140

The amount of air used is generally $1\frac{1}{2}$ times that theoretically necessary. If this proportion were increased, a larger proportion of heat could be recovered and consequently the consumption of fuel could be lessened. To completely recover this heat it would be necessary to employ from $2\frac{1}{2}$ to $3\frac{1}{2}$ times as much air as the theoretical proportion. But this would lower the temperature so much that it limits the amount of draught. In practice, a double volume of air must not be exceeded for the lower temperatures, and not more than $1\frac{1}{2}$ times the theoretical quantity should be ordinarily used.

General Arrangements.—Brickworks are essentially local factories, because of the large number of deposits of clay suitable for making bricks occurring in all countries, and also the great weight of the goods in comparison to their value.

Brickworks can be divided into three classes : (1) Those using moulding by hand and burning in intermittent kilns ; (2) those using hand-moulding, but burning in continuous kilns ; (3) those shaping the bricks by machinery and using continuous kilns. When the output is below 600,000 or 1,000,000 bricks per annum the first method is preferable, as there is a limit below which it is not economical to use continuous kilns. As a rule, also, the use of mechanical power is only advantageous when more than 10,000 bricks per day are made.

The maximum output of a continuous kiln is 25,000 to 30,000 bricks in twenty-four hours, which, allowing for stoppages, holidays, etc., is equal to a machine production of 30,000 to 40,000 bricks a

day. For a larger output two kilns are arranged side by side in two buildings, 40 or 50 ft. from one another, the making machines being between the two.[1] For more than 20,000,000 bricks a year, two or more independent plants must usually be built.

In all brickworks, the cost of transport must be kept as low as possible, and all unnecessary handling of the goods must be avoided.

(*b*) Hollow Blocks.

The manufacture of hollow blocks on a large scale only dates back to 1855, but the use of them has developed considerably since then. They are principally used for the construction of partitions, light walls, and for filling in the intervals between the girders in floors ; but in recent years they have been largely used for external

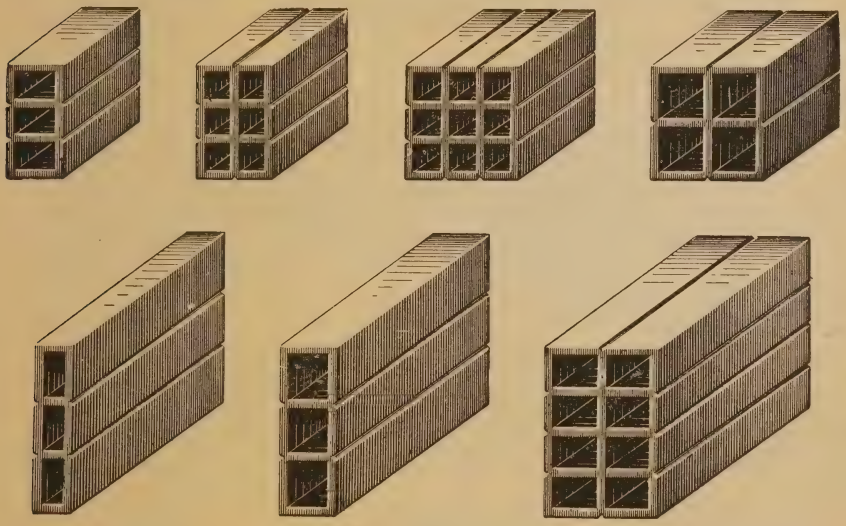


Fig. 209.—Hollow blocks.

walls as, if the dimensions are carefully chosen, such blocks are easier and cheaper to lay than common bricks.

Fig. 209 shows a number of designs of these blocks, generally used for partitions ; they are from 8 to 14 in. long, 4 to 9 in. wide, and 1 to 4 in. thick. It is usually convenient for them to correspond to a definite number of common bricks ; thus a block $18\frac{1}{4} \times 9 \times 6\frac{1}{4}$ corresponds to eight common bricks each $9 \times 4\frac{1}{2} \times 3$ in., allowing the joints to be $\frac{1}{4}$ in. wide. Fig. 210 shows examples of flooring blocks. Type I is used for light floors, and is from $15\frac{1}{2}$ to $22\frac{1}{2}$ in. long, 8 to $9\frac{3}{4}$ in. wide, and 2 to $3\frac{3}{4}$ in. thick. When the bricks rest on the lower wing of the girders of the floor it is

[1] Bührer has conclusively shown that suitably arranged kilns can work at double the rates mentioned above if the materials are right.

advisable to cut them as shown in the drawing, so as to make a place for the wing. Type II is meant for solid floors with a space between the girders of 2 to 3 in. The bricks are usually from $8\frac{1}{2}$ to $11\frac{3}{4}$ in. long by 4 to 5 in. thick. Type III is used for very strong floors intended to bear great weights.

Hollow bricks may be made in various other shapes, but to secure regular and economical working, the following dimensions should not be exceeded : 18 in. long, 10 in. wide, and $6\frac{1}{4}$ in. thick.

The bodies used for hollow bricks should be more plastic than those for making plain bricks. Hollow blocks are always made by expression ; the dies used for this purpose have been described in

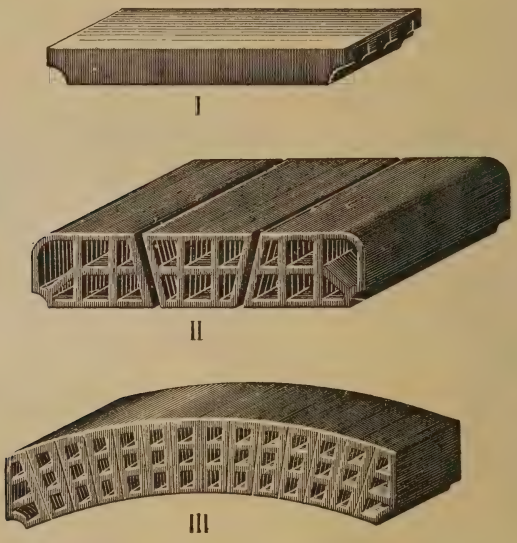


Fig. 210.—Flooring blocks.

Chapter V. For small goods piston propellers (" stupids ") are used (Fig. 64). For hollow bricks with larger dimensions than those already mentioned, a stiffer body must be used, as then there is less shrinkage and less liability to loss of shape.

The *drying* of hollow bricks presents no special difficulty. It is much quicker than that of plain bricks, and the blocks have much less tendency to get out of shape.

The *setting* is also easy ; the blocks are put in the kiln close to one another, the internal holes being sufficient to secure the circulation of the gases and flames.

The *burning* is also more rapid than that of plain bricks, and it is easier to spread the heat uniformly throughout the kiln.

(*c*) Ornamental Bricks.

When the bricks used in buildings are neither to be painted nor covered with stucco, the bricks (called *ornamental bricks*) are often used. These are usually distinguished from ordinary bricks by their more regular shape, the uniformity of their colouring, their finer grain, and their great resistance to the weather. The body must be better prepared and more carefully mixed than is usual for ordinary bricks, and it must, after baking, have the desired shade (p. 193).

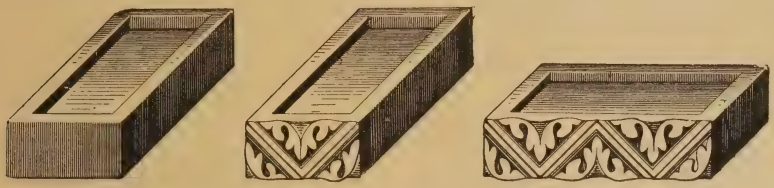


Fig. 211.—Re-pressed fancy bricks.

Ornamental bricks moulded by hand are not satisfactory, but must be re-pressed. The brick at the left of Fig. 211 shows the type of re-pressed brick most used. The dimensions are those of ordinary bricks; the width and thickness, however, are slightly increased, as the joint of 0·4 in. of brickwork is reduced to 0·2 to 0·3 in. for frontage work (*facing bricks*).

Figured bricks (Fig. 211) may also be obtained by re-pressing a copper plate with the desired pattern cut into it being fitted in

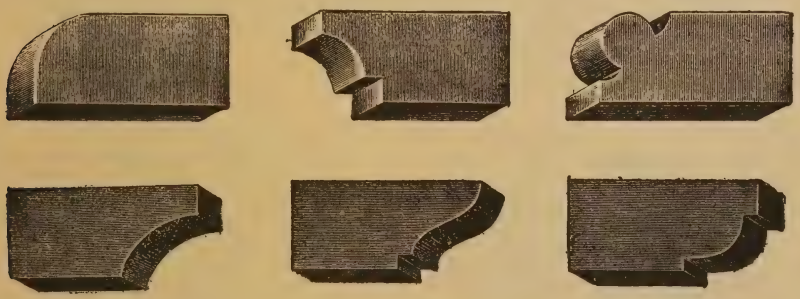


Fig. 212.—Fancy bricks for mouldings, plinths, etc.

the ordinary mould. The pressure forces the body into the hollows of the plate, which is taken out of the mould together with the brick; the plate is separated, cleaned, oiled, and replaced in the mould.

When pressed out of dry body, ornamental bricks may be made of accurate dimensions, and when well burned resist the inclemency of the weather, but the moulds used in this method are costly.

Shaping by expression is the best and most economical method

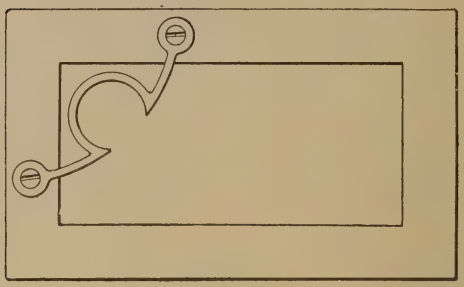
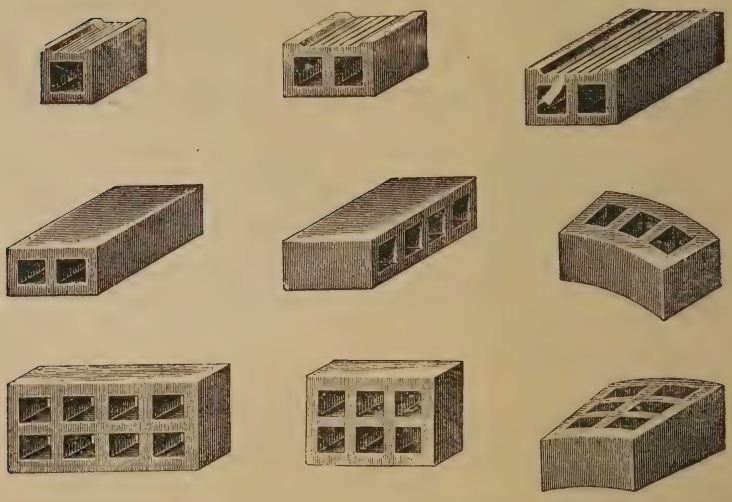


FIG. 213.—Die for plinth bricks.



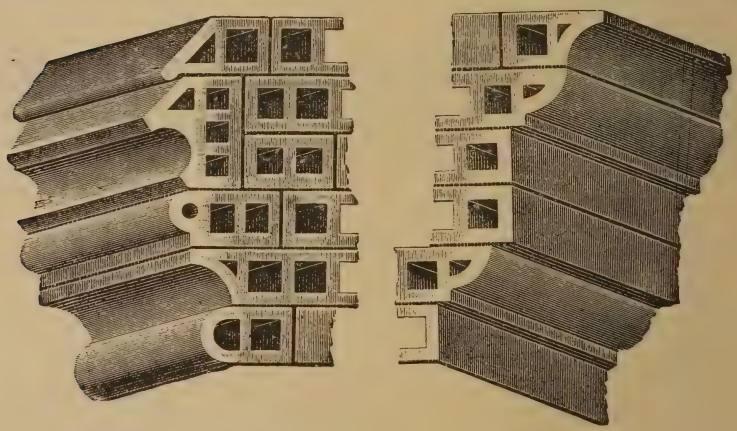


FIG. 214.—Hollow blocks.

of manufacture for ornamental bricks when it can be used, as the surfaces which have been in contact with the die plates have a regular grain of agreeable appearance, and a better colour than re-pressed bricks. Such bricks are sometimes re-pressed, but this should be avoided, because, with a little more care, better goods can be obtained direct from the mouthpiece. Bricks for mouldings (Fig. 212) are easily fashioned by fixing on the outer edge of the mouthpiece or die a small steel templet, with its edge turned towards the inside, the templet being of the shape of the profile desired (Fig. 213). The part of the body cut off by the templet remains on the brick, and is taken away when the latter is dry and before it is placed in the kiln.

When very regular ornamental bricks are required, and it is at the same time desirable to economize the raw material, it is better to use hollow blocks, as they are less liable to get out of shape while drying (Fig. 214).

Figs. 215, 216, and 217 show the mouthpieces used for ex-

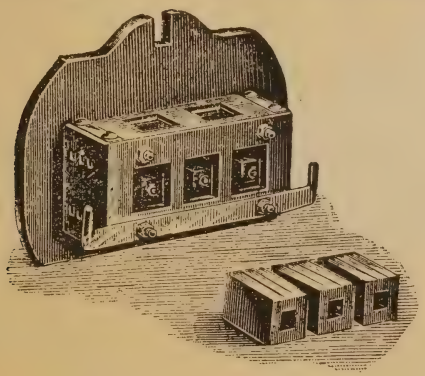


Fig. 215.—Die for hollow blocks.

pressing hollow blocks ; they are attached to a pug-mill or to an auger machine, the propellers of which have a single screw. To prevent the surface of the blocks from getting out of shape or being spoilt, they are taken from the cutting table with wooden forks, which are put into the holes in the blocks.

Ornamental bricks which are to resist the weather must be burned at a temperature high enough for them only to be scratched with difficulty by a piece of iron. They must be made of a body containing sufficient fluxes to vitrify slightly, and enough refractory material to prevent it from getting out of shape. Certain natural clays (terra-cotta clays) fulfil the requisite conditions ; when none are available they must be made by mixing other clays, etc., in suitable proportions. To obtain clear colours, the goods must not come in contact with ashes or flame, so that either gas-fired continuous kilns or continuous kilns with solid fuel are used, but certain precautions, which are mentioned later, must be taken.

When the body is not of a sufficiently uniform tint, or when the colour is unsatisfactory, the surfaces of the ornamental bricks may

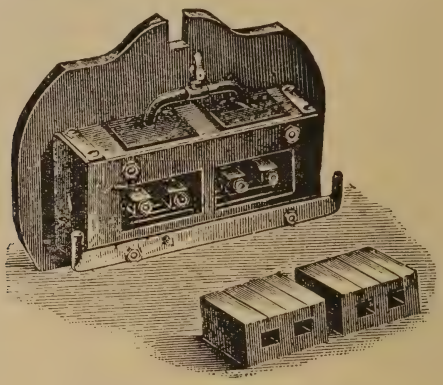


Fig. 216.—Die for hollow blocks.

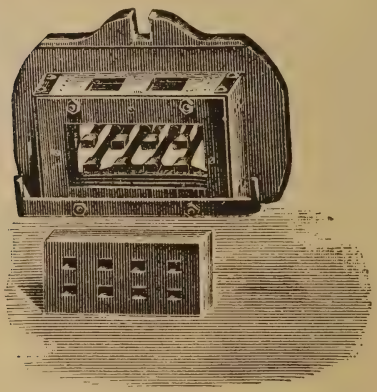


Fig. 217.—Die for perforated bricks.

be covered with slip, but it is seldom that really good results can be obtained from this method.

(*d*) Vitrified Bricks.

Vitrified bricks are so hard that they cannot be scratched by iron, and only with great difficulty by steel. They form the transition between terra-cotta and stoneware. They show, at least on the surface, the beginning of vitrification; their colour is light or dark reddish-brown—sometimes even almost black—or a brownish-yellow. In the first case, the body of which the bricks are made is ferruginous, and in the second, calcareous.

Vitrified bricks are sometimes used for ornamentation, but their

chief use is in masonry which has to bear great pressure, hence they are often called *Engineering bricks*.

They should contain a large proportion of fluxes, and also a considerable amount of crystalline silica in relatively large grains, so that while the bricks are being heated at a temperature high enough to vitrify the fluxes, the silica may remain uncombined and form a firm skeleton, which prevents the mass from losing its shape. Many natural clays fulfil these conditions ; to others, quartzose sand or fusible clays must be added.

Vitrified bricks are made by the same methods as the ordinary bricks, but the burning must be done at a higher temperature. They should not, however, be moulded by hand, as that makes them too porous. They are best burned in continuous kilns, but are chiefly fired in single kilns (Figs. 145 and 218), as the output is

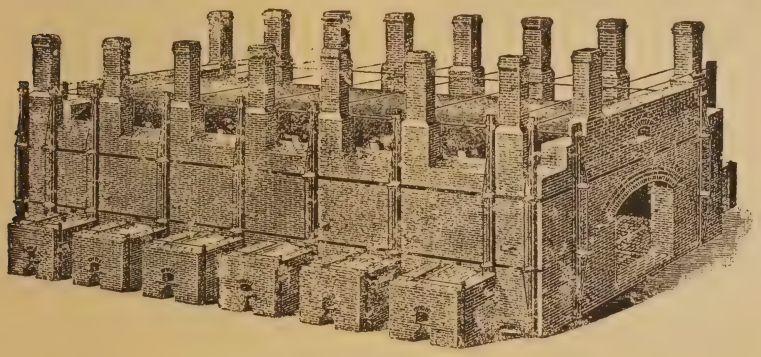


FIG. 218.—Kiln for paving bricks.

limited. In some countries, such as the Netherlands and the United States, and to a lesser extent in England, these bricks are much used for paving streets.

When wood is used as fuel, the ashes are carried along by the draught and are deposited on the surface of the bricks, forming, when the temperature is high enough, fusible alkaline silicates which cover the bricks with a thin vitreous layer.

Attempts have been made to obtain a similar effect in kilns using coal by throwing salt into them and by firing the kilns so as to produce a reducing atmosphere. If the body is decidedly ferruginous, dark bricks may be obtained with a certain metallic sheen, to which the name of *metallic bricks*, *iron bricks*, or *blue bricks* has been given.

(*e*) Light Bricks.

Light bricks are distinguished from ordinary bricks by their apparently small density and their great porosity. In America they are termed "Terra-cotta Lumber." They are made (i) by adding combustible materials to the body ; these are consumed in

the burning and leave spaces (see p. 39) ; and (ii) by using as much kieselguhr and volcanic lava as possible.

Some manufacturers of ordinary bricks add powdered coke, coal, cinders, sawdust, etc., to their clay, and thus obtain lighter goods, but these should hardly be reckoned as light bricks. The reduction in weight thus obtained is never very great, and is less important than the other advantages obtained, viz., more rapid drying, less shrinkage, more economical burning, etc.

If sufficient coal is added to a body to make it lighter, the heat produced in burning would melt the clay, so that light bricks can only be obtained with vegetable matter of a small calorific power. The substances most used for these purposes are wood, sawdust, and chopped straw. The clay must be very plastic, so as to bind together a very large quantity of organic substances, as under some conditions one-third of clay must be mixed with two-thirds of sawdust. The proportion of clay may even be reduced to one-fourth of the mixture by adding straw chopped up into pieces $1\frac{1}{2}$ to 2 in. long.

The body thus obtained must be worked in a pasty state either by hand in a mould with hinges or by forcing it through a mouth-piece, though as it cannot usually be cut by metallic wire the cutting tables may be replaced by circular saws. The die must be of small section, compared to the diameter of the screw, so as to compress the body thoroughly.

The drying is the same as for ordinary bricks. The burning can only be done in continuous kilns if the proportion of organic materials is adapted to the clay ; beyond this amount, the heat would be too great. The burning must then be in intermittent kilns, preferably with up-draught and with a current of air strong enough to keep the temperature of the kiln low. In all these cases, only enough fuel is used to start the fire and to produce an even distribution of the temperature.

The light bricks thus obtained can be sawn, turned, and even planed with tools similar to those used for working in wood. This kind of pottery is chiefly used in the United States as a light fireproof material for buildings.

The Romans manufactured bricks so light that they floated on water. They made use of volcanic silicious tufa, with the addition of a small proportion of clay. Infusorial earth can also be used.

Tiles : (*a*) Common Tiles.

The use of tiles dates from very ancient times. The Romans imitated the Greeks in this kind of covering, and the shapes used by these nations are wrongly called *Roman tiles* (Fig. 219), as this same pattern was used by the Chinese several centuries before our era, and since then by other nations of the Far East. Two moulds were used, one to form a fairly thick slab, with two side ridges, and the other a slightly conical semi-pipe. The slab is $15\frac{3}{4}$ to $31\frac{1}{2}$ in.

long, $9\frac{3}{4}$ to $20\frac{3}{4}$ in. wide, and 1 to $1\frac{1}{2}$ in. thick. The lap is about $3\frac{1}{8}$ in.

This tile is pleasing architecturally, and, in this respect, is superior to many modern tiles, but it is very heavy. In the Far East the round covering tiles are often decorated with floral designs, which gives the roof a rich ornamental appearance. This type of

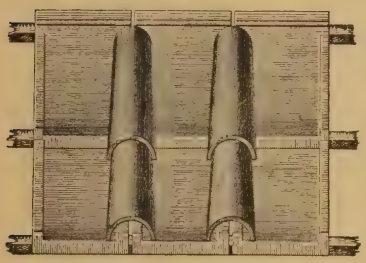


FIG. 219.—Roman tiles.

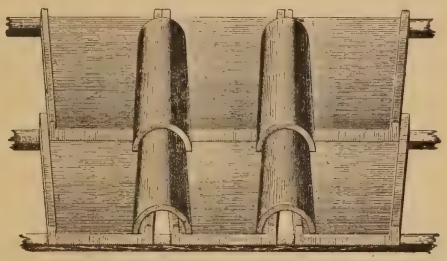


FIG. 220.—Mediæval tiles.

tile was in general use up to the tenth century, when it was modified to the pattern shown in Fig. 220, in which the slabs are of a shape which allows of their being covered without necessitating the pressing down of part of the mouldings ; this modification involves an enlarging of the covering tile, and a widening of the flat tile. The arrangement shown in Fig. 221 consists of round tiles somewhat conical in shape and overlapping each other,[1] the greatest diameter

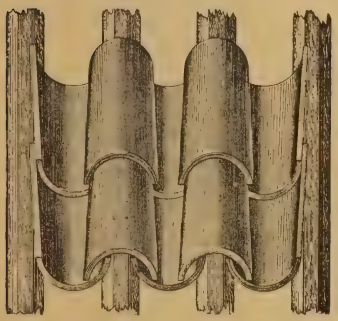


FIG. 221.—Round tiles.

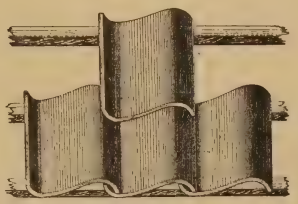


FIG. 222.—Pan-tiles.

being towards the top of the roof. These tiles are afterwards covered with similar tiles, arranged in exactly the opposite direction. The length varies from $16\frac{1}{2}$ to $19\frac{1}{2}$ in., and the greatest width from 7 to 9 in. It makes a heavy roof, but protects the buildings well from heat, and is popular in South Europe.

Pan-tiles (Fig. 222), having the shape of an elongated S, are

[1] These are often called hollow tiles, but this name ought not to be used.

evidently derived from the round tiles, but differ from them in form and by the addition of a small projecting piece to the lower face of the tile, which engages with the laths and allows of a steeply sloping roof. Pan-tiles have long been popular in this country, especially for cottages, barns and other farm buildings, but they are gradually being replaced by plain tiles and interlocking tiles.

Flat tiles or *plain tiles* (Fig. 223) are rectangular in shape, 10 to

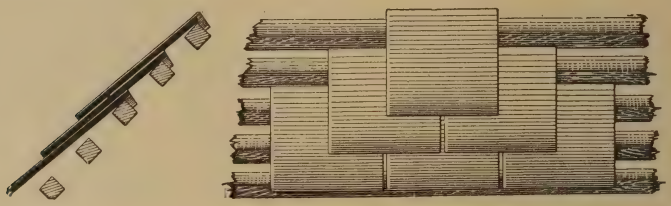


Fig. 223.—Plain tiles.

16 in. long, by 5 to 11 in. wide, and $\frac{1}{4}$ to $\frac{3}{4}$ in. thick. One or more hooks or *nibs* fasten them to the laths, and two-thirds of the surface is covered by the upper tiles. Sometimes holes are pierced in the tiles, which are then nailed to the laths.

By rounding the lower edges of plain tiles, *scale tiles* or *beaver-tail tiles* (Fig. 224) are obtained, the average size being 10 in. by 6 in. Sometimes the upper surface is grooved as shown in Fig. 225.

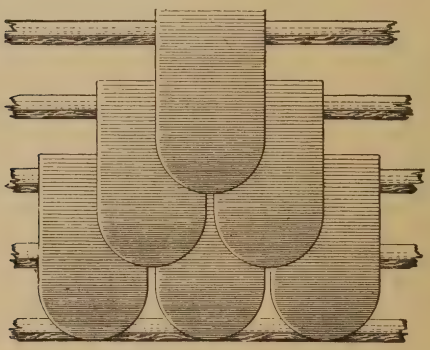


Fig. 224.—Scale tiles.

Fig. 225.—Ribbed scale tile.

Interlocking tiles are supplanting those already mentioned. There are many patterns, the following being typical :—

The *lozenge tile*, shown in Fig. 226, is $15\frac{3}{4}$ by $8\frac{1}{4}$ in.

The *Marseilles tile* (Fig. 227) is $16\frac{1}{2}$ by $9\frac{7}{8}$ in., and is largely used in France and England.

The *mountain tiles* (Fig. 228) are extensively used in Switzerland. They are 15 by $8\frac{1}{4}$ in.

Tiles somewhat similar to the preceding type, but hollow (Fig. 229), give a good insulation against variations in temperature. They are of various dimensions.

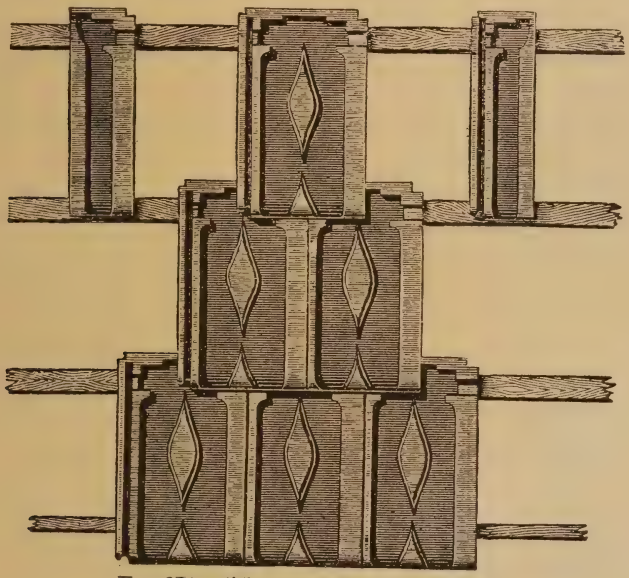


FIG. 226.—" Lozenge " interlocking tiles.

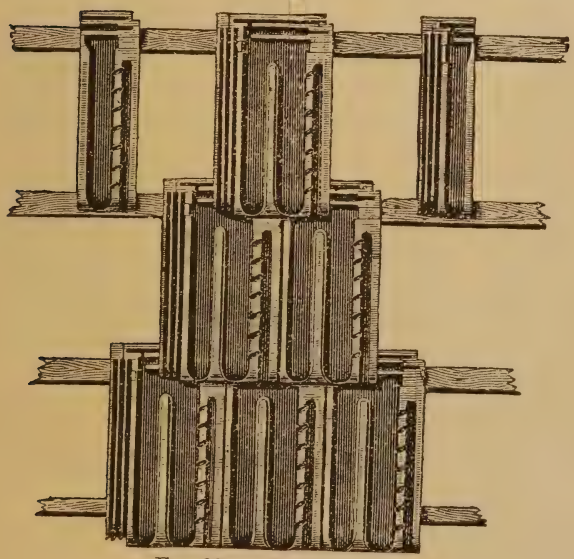


FIG. 227.—Marseilles tiles.

In addition to ordinary tiles, there are also used in roofing: *Ridge tiles*, for covering the ridge of the roofs; *cat-hole tiles*, with an opening for ventilation; *tiles with windows*, for lighting; *tiles with pipes*, used for passing ventilation or draught pipes through. *Finials*, *king-posts*, *borders*, *ends of borders*, *frontals*, etc., etc. Some designs for these different parts of the roof will be found in the catalogues of the principal manufacturers and need not be described here.

Fig. 228.—Mountain tiles.

The moulding of tiles needs much more plastic bodies than those used in the manufacture of bricks; the porosity of the body must also be considered, as it is necessary that the roof shall be impervious to rain and yet shall be sufficiently porous to have a slight ventilating effect, wholly impervious tiles not being satisfactory. Some architects prefer more porous tiles with a coarse, rough sur-

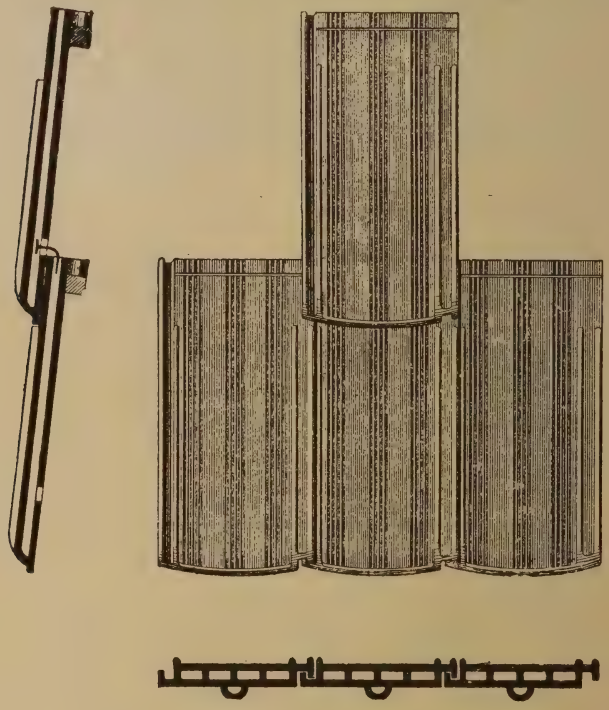


Fig. 229.—Hollow interlocking tiles.

face on which algoe and other vegetable matter will grow rapidly, imparting an aged appearance to the roofs. To meet this need,

some tile manufacturers dust the wet surfaces of the freshly moulded tiles with a mixture of chromic oxide and manganese dioxide.

To ensure impermeability to rain, the pores should be very small ; this is secured by using a body having a large proportion of true clay and a plastic material composed solely of small particles. In most cases the porosity of tiles is only a temporary defect, as the pores are quickly sealed up by dust in the air. Nevertheless, a high porosity, even though temporary, makes the tiles of less value commercially. Hence it is advisable to avoid the use of very soft bodies, which become more porous when dried. This is the chief defect in all tiles moulded by hand, though attempts have been made to lessen it by a great thickness of body and the use of glazes. Machine-made tiles are made of a stiffer body, and are, to that extent, preferable, providing that this stiffness is not excessive, whereby a more serious defect, viz., puffing-up or cracking, results.

The bodies must be carefully prepared, and must be as homogeneous as possible.

Moulding by hand was formerly the only method of making tiles, and it is still popular on account of the low capital expenditure involved and the general superior appearance of the tiles over those made by machinery.

Plain hand-made tiles are made in a similar manner to bricks in a simple frame mould the shape of the tiles. For pan-tiles a flat *bat* is first made in a frame mould, and this is afterwards bent to the required shape by shoving on a curved block or *horse ;* when partially dry the tiles are placed one at a time on another block and beaten to ensure their having the requisite shape.

The *nibs* are usually formed by turning over the end of the tile, either by the moulder's thumbs or by pressing them in a special mould ; the nail holes may be punched at the same time. The hook on a pan-tile is usually formed during the moulding, or it may be attached afterwards.

Interlocking tiles can also be moulded by hand by using two plaster moulds bearing the imprint of the upper and lower faces of the tile, but this method is costly, and is only used for the manufacture of finials, etc., which it would not pay to manufacture by machinery.

Plain tiles of various shapes, and also many interlocking tiles, are made by expression through a mouthpiece (*wire-cut process*), the resulting band being then cut into tiles by means of a wire-cutting frame similar to that used for bricks.

Interlocking tiles which cannot be made by the wire-cut process are moulded in a press, in a soft, stiff-plastic or semi-dry state.

Manufacture by Expression.—For the *wire-cut process*, the body is made into a stiff-plastic or soft paste, and it must be well mixed before it is put into a shaping machine ; this usually takes the form of a pug-mill with a suitable mouthpiece or *die*, similar to that used for making wire-cut bricks.

The die is usually in the form of a flat plate with a slot, the construction of it offering few difficulties. The chief interest in this method of making tiles is centred in the cutting apparatus, which differs for each shape of tile. For flat, rectangular, and thin tiles the nibs may be formed by folding back the body ; in another method, the clay paste forced out of the mouthpiece is passed between two rollers which are turned round by it. The lower one

Fig. 230.

has a projection which corresponds to a hollow on the upper roller, so as to press out the paste at regular intervals and to form a nib. A blade connected to the upper roller cuts the tile to the right length, after which it is put on to a rack or pallet by a workman and carried into a drying-shed.

For thicker, flat tiles this method is not applicable, and a piece is cut out of the mouthpiece, the same size as the section of the

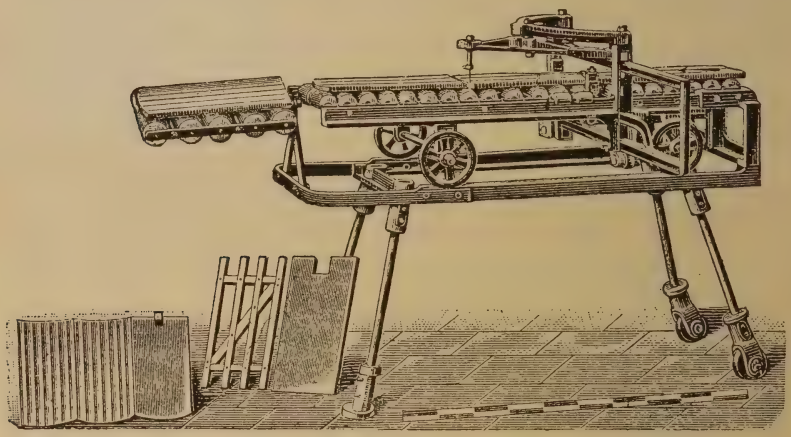


Fig. 231.—Cutting table for tiles.

nib, so that the body issuing from the machine is given the shape shown in Fig. 230, and is cut by a wire, *a*, *b*, except where it is left to form the nib. Fig. 231 shows an apparatus of this kind, constructed by Schlickeysen, in which the tile is cut in one operation to the shape and length shown in Fig. 225. When the cut tile reaches the end of the hinged board it is covered with a wooden frame, and the whole turned over by holding it in the frame with the hand, and carried to the drying-shed, while the hinged board is put

back into its original position ready for another tile. In this way 600 to 700 tiles an hour can be made.

Sometimes several tiles are expressed simultaneously, as shown in Fig. 232 ; the hollow mass thus produced is cut to the length of the tile by a first cutting apparatus, and is then pushed by hand into a second apparatus, in which a series of horizontal wires divide it up into four tiles, missing the parts of the fillets, *a*, which are to

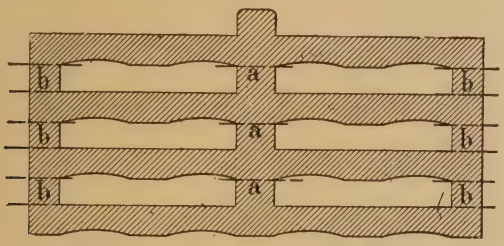


Fig. 232.

form the nibs. The whole block is then dried, and the tiles are separated, when dry, by taking away the small pieces *a* and *b*. About 1200 tiles may be made in an hour in this manner.

The interlocking tile shown in Fig. 228 is made by a cutting apparatus in the same way as the preceding tiles ; the body must afterwards be cut to the desired length and a part of the fillet be raised to form a nib or ledge. It is also necessary to press down a

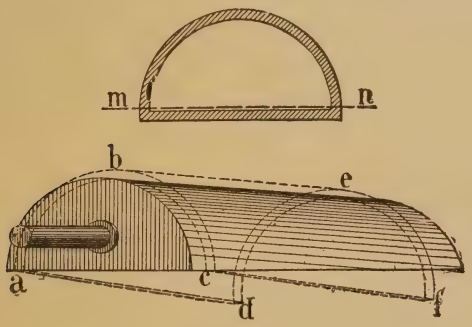


Fig. 233.

length equal to the projection of the mid-rib on the covering tile. These various operations are easily done by one workman. The tile arrives at the end of the board quite finished, is covered over by a frame, and taken to be dried, about 500 tiles an hour being made.

Some cutting appliances are furnished with punches, by which nibs or other projections, which it is impossible to get with a mouthpiece, are produced on the tiles.

Various very ingenious machines have also been made for forming round tiles which are of partially conical form. The following is one of the simplest: A length of body of the shape shown in Fig. 233 is passed out of the die, and is at once divided by a horizontal fixed wire, *mn*. The tile is then cut to the desired length, the upper curved part is lifted by a wooden conical block (Fig. 233) of the same shape as the interior of the tile. The sheet of clay, being plastic, fits the block following the dotted lines *abc*, *def*, and is cut with a steel wire and placed on a board. This process allows 250 round tiles to be made in an hour. If preferred, they can be made equally well by a press.

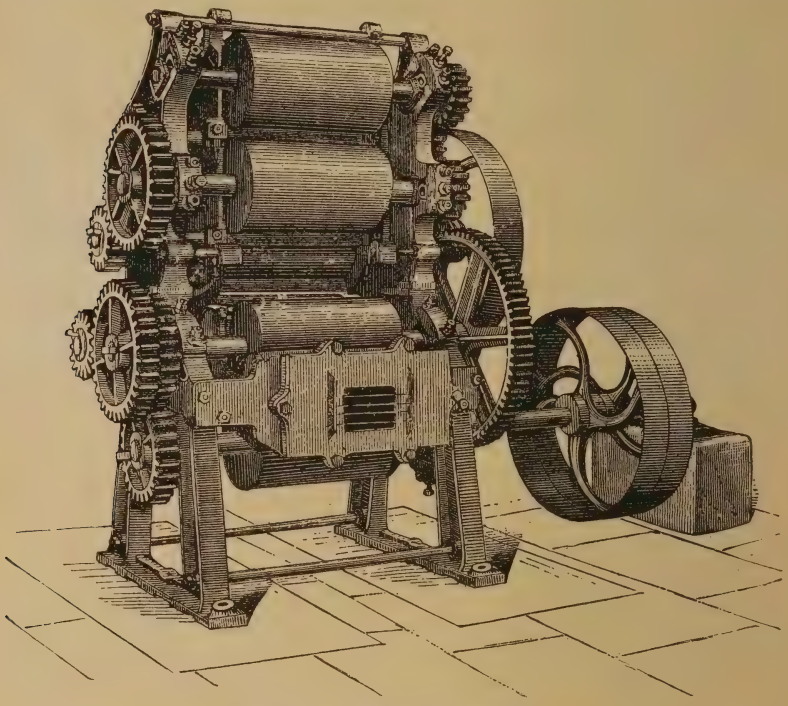


Fig. 234.—Bat-making machine.

Manufacture in a Press with Soft or Stiff-Plastic Body.—As it is impossible to press a soft paste rapidly into the form of tiles, the manufacture must take place in two stages: (*a*) in which the material is roughly shaped to form a *bat*; and (*b*) in which the rough *bat* is accurately shaped. The bat is usually made by the wire-cut process, a machine being used which crushes and prepares the body as well as producing bats roughly corresponding to the tiles. Sometimes the prepared body is so tender that it cannot be shaped in a pug-mill and die, and expression rolls must be used. Fig. 234

represents an example of a machine of this kind, with the expression rolls surmounted by two pairs of crushing rollers, which will manufacture about 1000 slabs an hour.

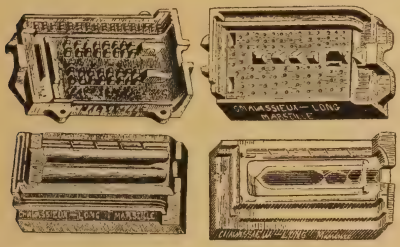


Fig. 235.—Patterns and moulds for tiles.

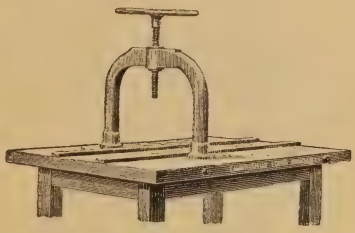


Fig. 236.—Press for making plaster moulds.

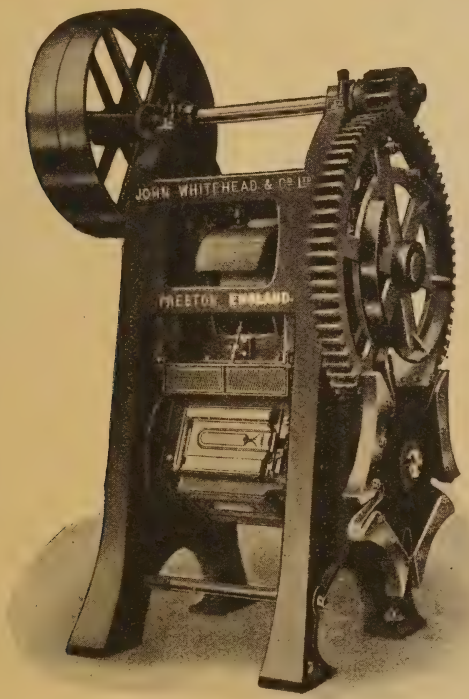


Fig. 237.—Whitehead revolving press.

The *bats* are then put into a heap, kept damp for twenty-four or forty-eight hours, and are afterwards separated from one another and placed in a press (p. 237). Some bodies permit metal dies or moulds to be used in the press, but others cohere so closely to metal

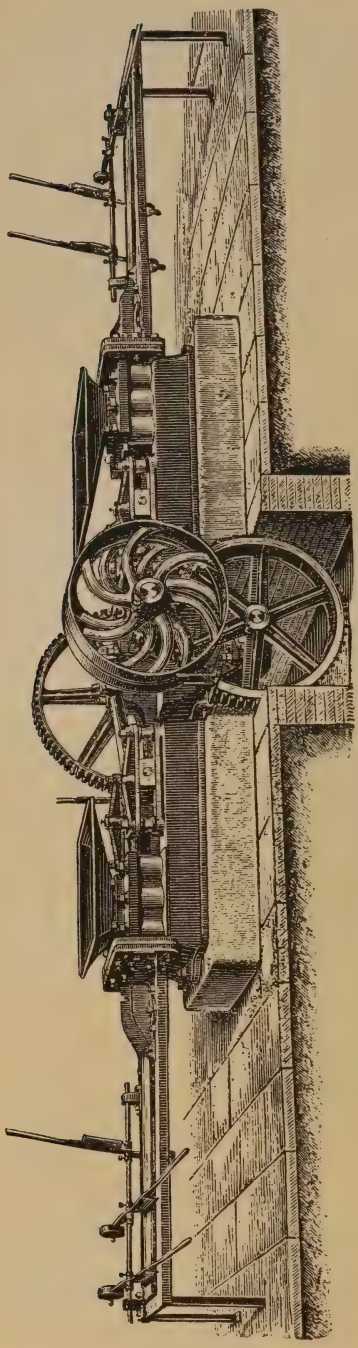


Fig. 238.—Slab-making machine.

(even when it is oiled) that the metal must be covered with plaster previously cast into shape by means of two patterns made of polished cast iron, which are a reproduction of the upper and lower faces of the tile. When the pattern has been removed the plaster is kept for twenty-four hours to harden ; it is then soaked in water for an hour. The mould is then ready for use, though the amount of moisture in the mould which will give the best result must be found by trial.

The upper part of Fig. 235 shows the two moulds, and the lower part the two patterns of a Marseilles tile, and Fig. 236 the press used in making the moulds.

The presses used for making tiles of soft or stiff-plastic paste are operated by tappets, eccentrics, or toggles, and act by steady pressure. Fig. 237 represents a machine of this kind. The mould or die forming the face of the tile is attached to the plunger of the press, and a series of moulds for the back of the tile are mounted on a revolving plate, so as to be brought in turn beneath the plunger. In another form of press only two lower moulds are used ; they slide to and fro and are used alternately, one tile being pressed whilst the other mould is emptied and a fresh bat placed thereon. With the revolving mould about 500 tiles can be pressed in an hour, two men being needed for each press.

The tiles, when thus pressed and placed on boards, are car-

ried to the drying-sheds, where, after having acquired the consistency of a leather-hard body, they are cleaned from the arris, caused by

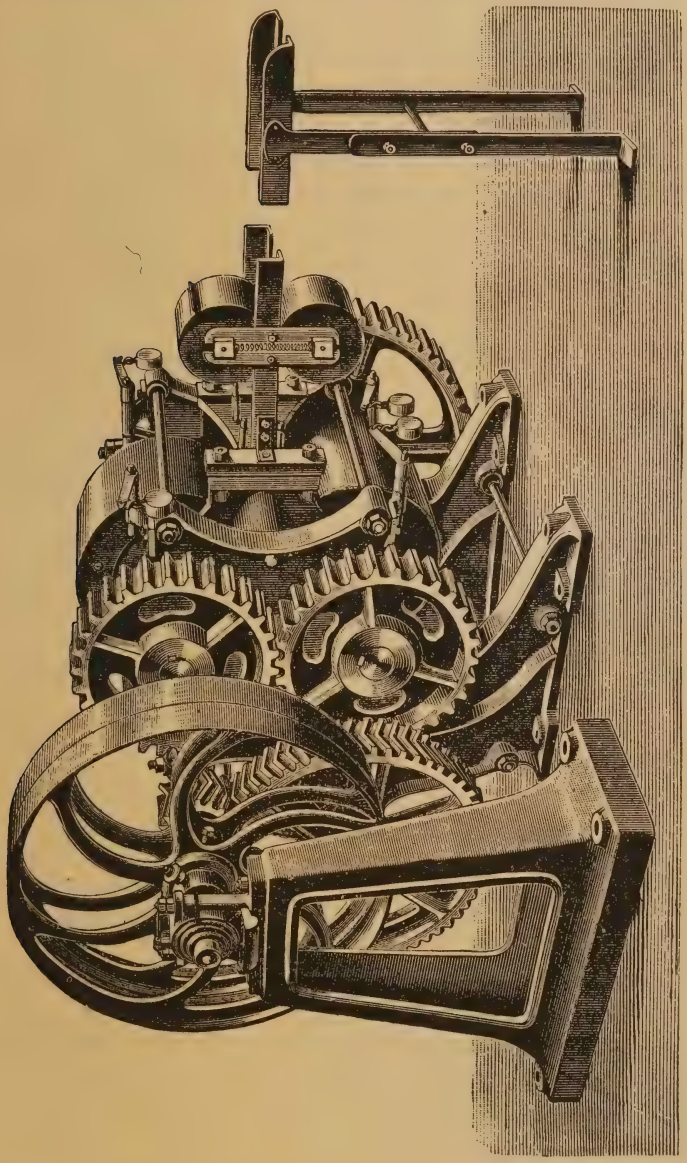


Fig. 239.—Slab- or cake-making machine.

the body oozing out between the two parts of the moulds during the pressing; this process is sometimes known as *dressing*. The drying is then completed, after which the tiles are ready for the kiln.

Manufacture in a Press with Semi-dry Body.—The moulding of tiles from a semi-dry body is similar to moulding from a soft or stiff-plastic body ; but stronger presses must be employed, because of the greater pressure required. The body must be prepared as described on page 98. Screw-propellers cannot be used, and it is necessary when making the bats to use piston propellers (" stupids "). The machines used for hollow blocks are specially suitable for this purpose. Fig. 238 shows a double machine of this type, so that use is made of the movement of the piston in both directions. Fig. 239 shows a machine constructed by Boulet et Cie for making bats, in which the body after coming out of the die is forced to pass between the two rollers, one of which has a knife-edge to cut the body into pieces corresponding to the length of the tiles.

The moulds used for semi-dry body cannot be of plaster as that would so soon be broken ; polished cast-iron moulds which are oiled to prevent the body from sticking are therefore employed. The bat may also be greased before it is put into the press. Screw-presses are principally used, as shown in Figs. 90 and 91 ; in the latter, the bat is put into the lower mould, which is in the position shown in the engraving, and it is then pushed under the upper mould. By working the side lever, one of the vertical discs presses the upper horizontal fly-wheel and causes the screw to rotate. The pressure exerted is in proportion to the actual force accumulated in the fly-wheel. By a second movement of the lever the other disc is made to move the screw up again. The lower mould is then brought forward and turned over. This type of press can make about 350 roofing tiles an hour.

Eccentric presses are also used, but they give a definite pressure and are less useful than the preceding friction-press, which allows the pressure to be graduated by the motion given to the screw, and also permits the use of two or more successive pressures. When the tiles come out of the press they are placed on a turn-table and trimmed by hand. The use of a clipping machine has not proved satisfactory.

Fig. 240.—Drying lath for tile.

Drying.—Only when the tiles are made of body which is almost dry can they be dried on shelves without being supported by wooden frames. The shape and dimensions of the frames or pallets depend on the shape of the tiles. Fig. 240 shows the usual shape for plain tiles, viz. three wooden strips nailed on two cross-pieces. As the drying on these frames takes from ten to twenty days, unless artificial drying is employed, the number of pallets used, even in a small tile works, is very large. They must be made of good, dry wood which will not easily warp in contact with the damp body when fresh moulded, as the warping of the pallet naturally involves that of the tile as well.

The tiles on their pallets are carried into the drying-sheds in the same manner as bricks. Wagons are seldom employed, and the wheel-barrows, instead of being flat, are usually of the kind shown in Fig. 241.

The tiles are generally dried in large, well-ventilated buildings over a continuous kiln, the waste heat from which is thus used. Other types of drying-sheds, previously described, can also be used.

As tiles weigh $2\frac{1}{2}$ lb. to 12 lb. each, the amount of heat and the volume of air required for drying them are about the same as for plain bricks, and the same calculations may be made. The duration of the drying ought to be much shorter on account of tiles being so much thinner, but in practice they often take quite as long to dry because of their much greater tendency to twist and crack.

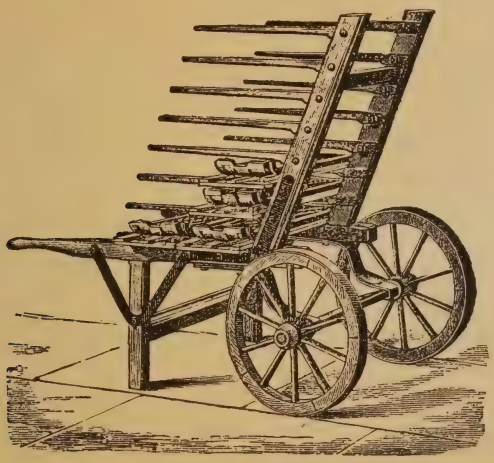


Fig. 241.—Tile-barrow.

The burning is best effected in continuous kilns, except for small quantities, when single (Fig. 143) or semi-continuous kilns may be used. The fuel and ashes should be kept from contact with the tiles. When, as is usual, plain or hollow bricks or tiles are made at the same time, it is wise to use the kiln shown in Fig. 206, the bricks being used to form the heating shafts, and for the bottom four or more courses in the kiln. This method of setting, which needs 40 to 69 per cent of bricks, is shown in Fig. 242.

The manner in which the tiles are placed in the kiln depends on their shape. They are usually placed in pairs, being leaned against each other so as to take as little room as possible, and to protect the nibs and other projecting parts. Interlocking tiles are packed close together, sufficient spaces being left between them to ensure the circulation of the gases and flames.

Round tiles are placed upright on one another. Flat tiles are

not so easy to set with sufficient space between them to ensure the necessary draught; when they are thin they cannot be set in bulk, but must be put in slips, using bricks or special pieces when necessary, to form cases for them. This method of setting may also be used for other tiles.

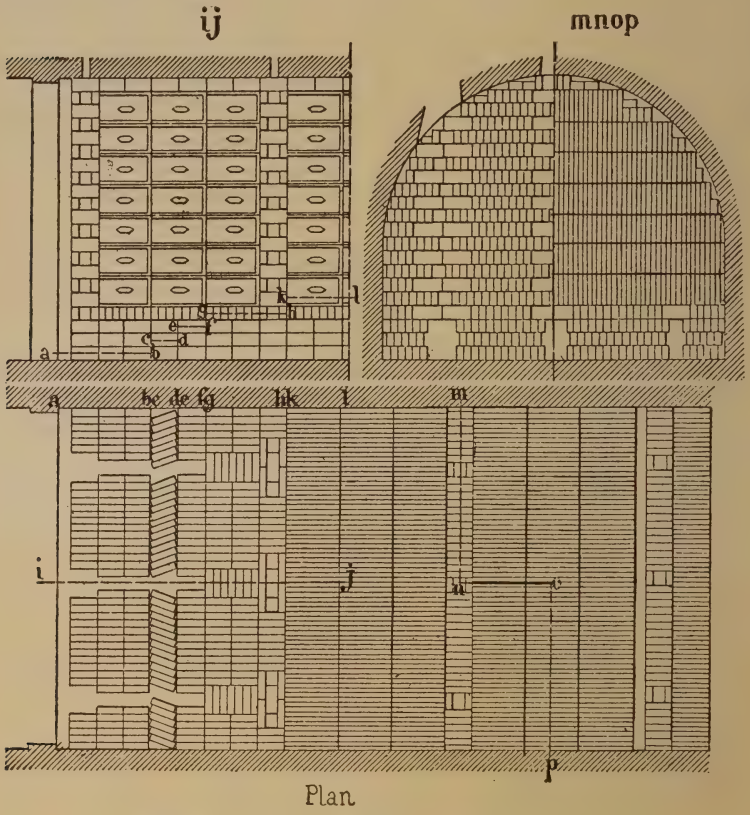


FIG. 242.—Arrangement of tiles in continuous kiln.

Tiles are burned at a temperature approaching that of vitrification, but not so high that they will lose their shape. The simultaneous burning of hollow bricks and tiles gives excellent results. As tiles are thin, the burning can be rapid, and the thermic yield of the kiln is greater than when common bricks are burned. By admitting double the proportion of air theoretically necessary, the kiln can be made to work with the following thermal conditions :—

Heat from combustion of fuel	100	Heat theoretically necessary for tiles	100
Heat regained from cooling goods	50	Heat lost by heating the walls	20
		Heat lost by radiation	25
		Heat lost through the chimney	5
	150		150

Thus under favourable conditions the yield of the kiln may reach 100 per cent, the heat regained compensating the heat lost.

When it is necessary to make tiles exclusively, the heating shafts may be replaced by a series of fixed furnaces built of fire-bricks, the furnaces being 6 to 8 ft. apart. Fig. 243 shows an arrangement in which the fuel, thrown in through a central opening, falls on the bricks arranged in steps between the two walls, half a brick thick, the air following the path shown by the arrows. The ashes remain between the walls. This arrangement makes it much more difficult to control the kiln, much space being lost in setting, and the furnaces must frequently be cleaned and repaired. Hence it is better to use grates or producer-gas. Fig. 244 shows a gas-fired kiln in which the gas coming from the producers through two lateral flues is carried to the burners by movable iron pipes. The setting is

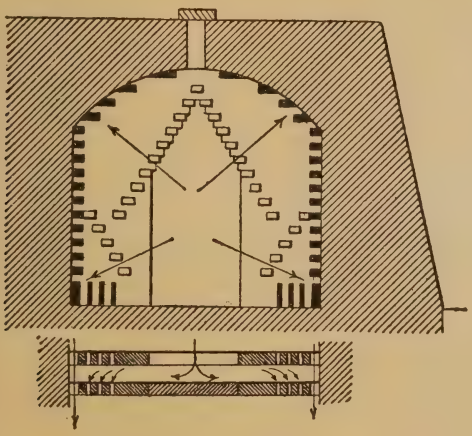


Fig. 243.—Haedrich's fireplace.

done in the chambers (A), leaving between them a space in which are the burners where the combustion of the gas takes place ; the gas flames are at right angles to the air. The working of this kiln is the same as that shown in Fig. 206, except that gas is used.

Gas-firing does away with the defects due to the contact of the fuel, the heating is more rapid, and the temperature more easily regulated ; on the other hand, it is more costly to instal, and the thermic yield of the kiln is lessened by the loss due to the gasification of the fuel in the producer.

Continuous kilns with grates (p. 231) also solve the problem of the exclusive burning of tiles. Fig. 245 shows a kiln of this kind. In such kilns, the air necessary for combustion is passed directly under the fire-grates and cannot be accurately controlled, so that usually the kiln works with an excess of air. This may be made to yield up most of the heat in it by preheating the tiles before the

kiln gases enter the chimney. The thermal balance of a kiln with grates is approximately :—

Heat from combustion of fuel	100	Heat theoretically necessary	90
Heat regained from cooling goods	65	Heat lost by heating the walls	20
		Heat lost by radiation	25
		Heat lost through the chimney	5
		Heat lost through incomplete combustion	25
	165		165

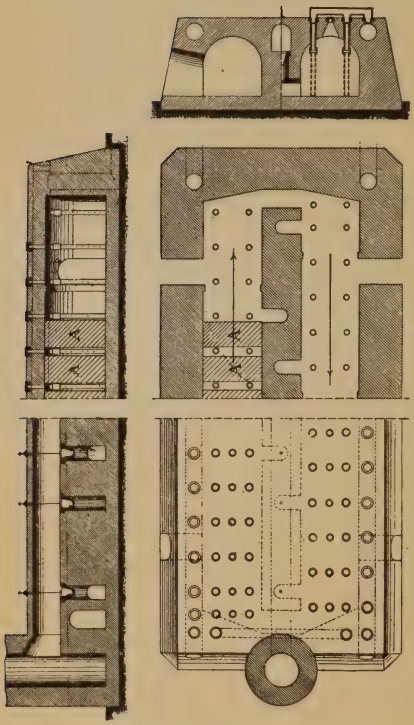


Fig. 244.—Gas-fired continuous kiln.

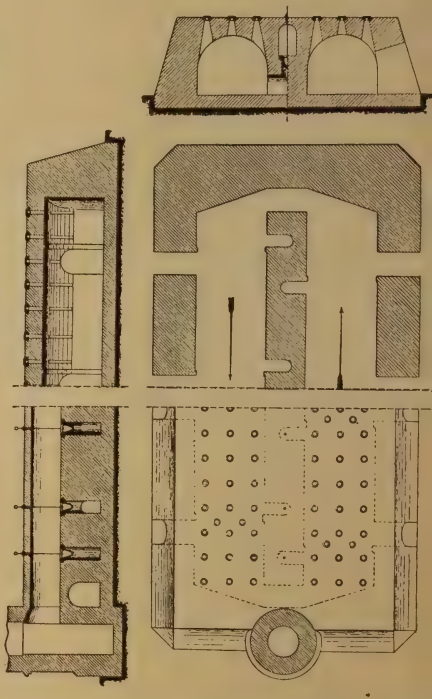


Fig. 245.—Continuous kiln with fire-troughs.

The thermal efficiency is reduced to 60 per cent, as so much less heat is recovered.

General Arrangements of a Roofing Tile Works.—The value of roofing tiles is 2½ to 3 times as great, in proportion to the weight, as that of plain bricks, but clays suitable for the manufacture of tiles are less widespread, so that many roofing tile works can sell these products over a wider area than brickfields. On the other hand, tile works tend to be concentrated in certain areas, so that competition among different manufacturers is often keen.

The cost of transport is also very high compared with the value

of the tiles. Small tile works which cannot use continuous kilns can only succeed under favourable local circumstances. Most roofing tile works are placed by the side of clay pits ; it is only in very exceptional cases that the raw materials are transported and made into roofing tiles near the larger centres of consumption.

The differences in the methods of manufacture employed in the tile works are not sufficient to make variations in their general arrangements important. All the tile works recently constructed on the Continent consist of large buildings over the kilns, containing rooms for preparing bodies and for making tiles on the ground floor, while the upper floors are used as drying-sheds. In England no one arrangement can be said to predominate over any others, though the tendency is towards the one just described.

(*b*) Black Tiles and Blue Bricks.

The so-called " black " of unglazed terra-cotta may be obtained by five methods : (1) Colouring the body by means of manganese oxide ; (2) by an application of a black slip to the body ; (3) by dipping in tar ; (4) by burning in a reducing atmosphere charged with hydrocarbons ; (5) by burning in saggars containing powdered carbon.

The first two methods have already been described, but are costly and are seldom used for ordinary terra-cotta articles.

Tarring or dipping the goods in liquid tar is principally used for roofing tiles. For this purpose, the tar must be sufficiently fluid to penetrate the pores of the terra-cotta ; so that it must be used hot. If cold terra-cotta articles are dipped in tar they absorb it only on the surface, and the black colour quickly disappears under the action of rain, but by heating them first to 50° to 60° C. the tar penetrates to a depth of $\frac{1}{8}$ in., and gives a dull unglazed black. Tarring does not appreciably help the terra-cotta to resist the weather, but rather the opposite.

The process of producing black terra-cotta by means of a special kind of burning is technically known as " blueing," because the black articles have a bluish metallic sheen. The kilns for blueing (on account of the extremely reducing atmosphere used for finishing) are usually intermittent, though when a suitable continuous kiln can be used it effects a great saving in fuel.

Blue bricks and tiles are made in England from a ferruginous clay showing at least 5 per cent of ferric oxide on analysis. The setting and the greater part of the burning of the bricks and tiles is done in the same manner as when common bricks are burned, but when the ordinary firing is ended, the fires are banked up heavily with coal and the air restricted as much as possible. As a result, the conditions in the kiln (with a suitable coal) become intensely reducing, and the bricks or tiles become blue throughout owing to the formation of ferrous oxide or of magnetic (ferrosoferric) oxide, which rapidly combines with silica and forms the " blue " colour. If the bricks or tiles are overheated, and so vitrified prior to creating

the reducing atmosphere, they cannot be " blued," and if the blueing process is commenced at too high a temperature the goods may become impervious prematurely, with the result that their core will remain red or brown. When the reducing action is presumed to be sufficiently advanced, all openings into the kiln must be tightly closed, so that no air can enter during the cooling or reddish patches of re-oxidized iron oxide or silicate will be formed, and *brindled bricks* or tiles produced.

Many attempts have been made to produce black or blue bricks and tiles without the use of the particular quality of coal used for that purpose in Staffordshire and Yorkshire—the chief centres of the blue-brick trade. These alternative methods are not much used in this country, as they are unnecessary, but they have attracted much attention abroad. Thus, Fig. 246 shows an intermittent kiln designed by O. Bock for this purpose, in which a series of horizontal kilns placed side by side communicate with a chimney through a central underground flue. The heating is by two fireplaces—one at each end of each kiln. Two pipes with funnels are used for pouring

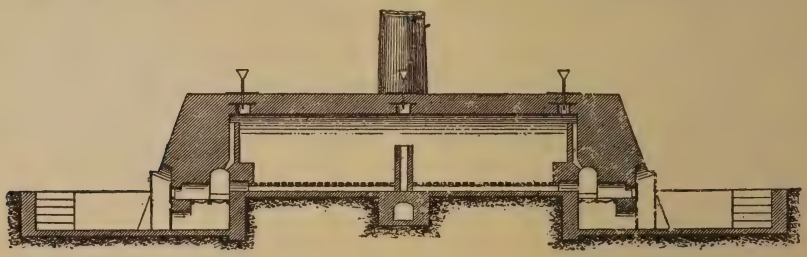


Fig. 246.—Kiln for blue bricks.

in the oil. As the cooling lasts seven to ten days, not more than two burnings a month can be done. The filling, warming, and chief part of the burning are done in the same way as for ordinary bricks, and only when the maximum temperature has been reached the special operation of blueing commences. For this, the burning space is entirely isolated and liquid hydrocarbons, such as tar or the oils arising from distillation of petroleum, are poured through the pipes previously mentioned. Under the influence of heat, these bodies are decomposed, and the deposit of graphite formed in the interior of the pores of the bricks or tiles colours the whole mass. If the bodies do not contain iron, or if the latter is combined with the lime in them, the colour is a dirty greyish-black. If, on the contrary, the body is ferruginous, ferrous oxide or even metallic iron is formed, and gives a very beautiful blue metallic sheen to the terra-cotta. From $17\frac{1}{2}$ to 55 lb. of oil are needed for a thousand plain roofing tiles, this oil being added in two or three portions at intervals of one or two hours. It is absolutely necessary for the kiln to be air-tight, as air would burn up the graphite, as long as the temperature of the goods is above dull red. Below this temperature the cooling

may be hastened, without disadvantage, by an opening in the top of the kiln or by raising the chimney damper, but above it too many precautions can scarcely be taken to keep the kiln closed and prevent air from getting in. Tiles and other small articles may also be blackened or "blued" by putting them with powdered coal, coke, or charcoal into saggars or in a "box" formed of bricks or terra-cotta slabs. There is thus formed in the saggars or boxes an extremely reducing atmosphere, which acts in the same way as that in the blueing kilns. Although this method has the advantage of not needing special kilns, the difficulties of filling the saggars and of controlling the colour are great, so that it is scarcely used except for some paving tiles and ornamental pottery.

Paving Bricks and Tiles.

Paving bricks and tiles are used both for paving and for walling, where great strength or impermeability are required. Paving bricks and tiles may be of any convenient shape, though the tiles are usually square or hexagonal: the side of each varies from 4 to 12 in., the most usual size being 6 in. The thickness depends on the other dimensions, on the method of making, and on the nature of the body; it varies from $\frac{1}{4}$ to 3 in.

The body used for paving bricks and tiles is often the same as that for making other bricks and tiles, and the methods of shaping are identical. It is in the burning where the chief difference occurs, black or blue bricks and tiles being burned as described in the previous section, and buff or red paving tiles being heated sufficiently to render them impervious to water. It is obvious that for such tiles only those bodies can be used which will not warp or twist unduly when so heated.

Ordinary paving bricks are laid in a bed of mortar for use, and have the disadvantage of showing the joints all round them. This defect may be remedied in tiles by giving them the shape of an inverted truncated pyramid, the tiles being larger at the top than at the bottom, so that when they are laid the tiles touch and do not let the joints show, the mortar settling in the triangular space formed between the two tiles.

The repress shown in Fig. 247 is excellent for making hexagonal tiles of this kind. Its chief disadvantage is that there is more pressure on the lower face of the paving tile, while the opposite would be better. Care must be taken to put the rough bat on the mould in such a way that no air bubbles can remain under it, as these would cause defects on the face. Such moulds can readily be adapted to all the presses already described.

Paving tiles are generally stacked two and two, with their faces in contact, and are thus placed in the drying-sheds. When they are thin, it is necessary to dry them in piles, the upper tile being covered with a burned one on which rests a brick or other weight. This makes the drying very slow, but it must be employed in order to obtain flat tiles.

Paving tiles may be burned in any kilns used for tiles. Thick pavers may be set in pairs by putting them in flat, so as to leave spaces. Thin paving tiles should be piled to prevent them warping, and the other goods set at the same time should be placed so as to prevent these piles from falling. The tiles must be "smoked" very slowly and carefully before the burning. If at the commencement of the firing any traces of damp remain in the piles, ugly

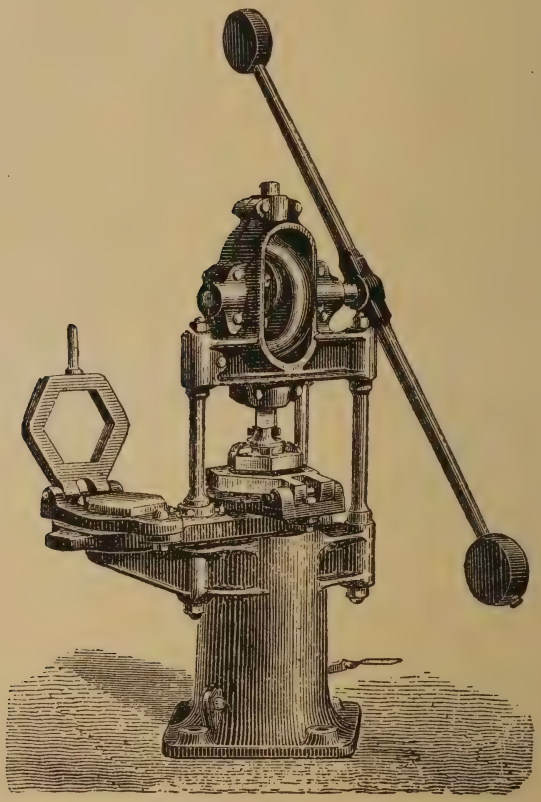


Fig. 247.—Press for paving tiles.

whitish blotches are formed on the tiles. The precautions which must be taken during the drying and burning make the manufacture of paving tiles more difficult than that of most other terra-cottas used for building purposes.

Pipes.

Pipes (Fig. 248) are used for flues, chimneys, ventilators, drainage, and for many other purposes. They are of varied shapes, the de-

scription of which belongs rather to the art of building than of pottery, because, whatever the arrangement employed, the methods of manufacture are largely the same.

Type I are round pipes, with a spigot at one end; they are usually 5 to 10 in. in diameter and 11 to 20 in. in height, and are chiefly used for land drainage and in chemical works.

Pipes used for sewerage purposes are similar in shape, but usually have a socket at one end sufficiently large for the opposite end of another pipe to fit it fairly closely.

Type II are rectangular with rounded corners, the interior dimensions varying from 5 by 7 in. to 10 by 12 in., with a height of 12 to 20 in.

Type III are chiefly built into walls to form flues; they are made

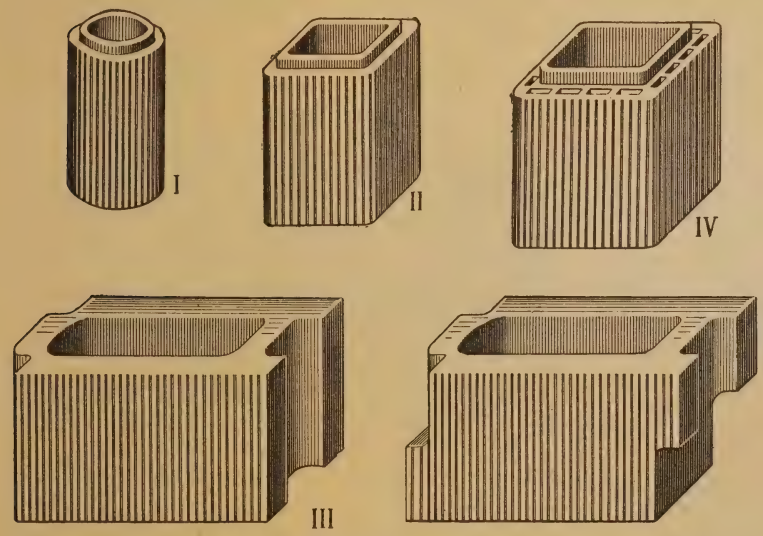


Fig. 248.—Patterns of flue-blocks.

straight or sloping, and with or without projections to keep the pieces together better. In some cases, the walls are made hollow (Type IV).

The body used for these pipes is the same as that used for hollow bricks. Plain pipes are made by squeezing out a soft body or plastic paste through a mouthpiece fitted to a running-out machine or "stupid" fitted with a piston or propeller, and generally worked by power. Fig. 65 shows a machine of this kind in which a metal cylinder is filled with body, so that when the propellor is set in motion by a rotating gear, it forces the body to pass out through a die below. The pipe thus formed rests on a balanced platform (Fig. 65), which descends with it. When the pipe is of the desired length, the workman stops turning the crank but keeps it in position, and

a second workman slips a metal wire along the frame, and cuts off the pipe. The platform is pushed a little lower and the moulded pipe is taken away on a board to the drying-shed. By means of a pedal the platform is raised again ready to make a second pipe. This is continued until there is no more body in the machine. The piston is then raised and, after refilling, the process is again continued. During the time of stopping for cutting the pipes it is necessary to keep the crank in place, as the compressed air in the body of the cylinder would otherwise raise the piston and produce inequalities in the pressure, which would cause defects in the pipes. These machines make forty to eighty pipes an hour. In larger factories continuous machines are used, and are described later.

When pipes with sloping ends are to be made, plain pipes may first be made and, when they have stiffened slightly, they may have the surplus clay cut off with a wire, leaving the ends of the pipe of the desired shape.

The *spigot* ends (Fig. 248, type I) are formed either by a special

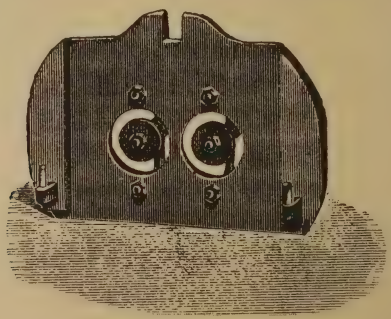


Fig. 249.—Mouthpiece for small pipes.

attachment to the mouthpiece which forms the spigot, or by cutting the requisite amount of material off a plain pipe. The *socket* ends of pipes are also made by attaching a special fitment to the mouthpiece which forms the socket, and is then removed or released ; the remainder of the pipe is then formed as described.

The pipes are usually *dressed* or *fettled* to remove superfluous material, and to remedy any defects. They are then dried whilst standing upright—usually in rooms with steam-heated floors.

Such pipes are burned in similar kilns to bricks or tiles. In filling the kiln the pipes are arranged vertically on one another, two pipes of different sizes being placed inside one another in the lowest course of pipes.

Pipes for conveying water were formerly made of terra-cotta, but except for agricultural purposes, they are now replaced by stoneware pipes.

Land or agricultural drain-pipes cannot be made of stoneware, as they must be porous. They are simple cylinders 2 to 8 in. in diameter inside, and are joined by placing their ends together ; the

ends are sometimes inserted in a short piece of pipe of a larger size. These pipes are pressed out of machines similar to those used for hollow bricks ; for this purpose dies similar to that shown in Fig. 249 are used. With pipes of large diameter only one is made at a time, while with small sizes, two, three, or even four pipes can be made simultaneously ; they are cut with a wire such as is used for bricks. The burning is done in brick or tile kilns, the smaller pipes being placed inside the larger ones.

Sewerage pipes made of stoneware are made in a similar manner, the sockets being formed as described on page 426.

Glazed pipes used for sewerage should, strictly, be made of stoneware, so that, even if the glaze is damaged, the pipe will be impermeable ; many of them are, however, made of fireclay, and so are porous except where covered with a glaze. The methods used for glazing such pipes are described in Chapter XII, that known as *salt-glazing* being the most widely used.

Architectural Terra-cotta.

Numerous kinds of terra-cotta are used in building that do not belong to the foregoing classes. Most of them are decorative, and made either from patterns belonging to the manufacturers or according to the original designs of the architect or the decorator.

The bodies used in the manufacture of these architectural terra-cottas should be plastic enough to lend themselves to hand-moulding and to modelling. The body must be very carefully prepared ; it should be somewhat fine, and preferably should have an impervious surface when burned ; if the terra-cotta has a rough surface, it would catch impurities in the air and would quickly look dirty.

In some cases, making by expression or turning may be employed, but hand-moulding in plaster moulds is largely used. If the number of pieces is very few, the expense of the moulds may considerably increase the cost of the terra-cotta. It is difficult in terra-cotta to obtain long straight pieces, such as handrails or balustrades ; hence it is better to make smaller pieces and to join them together.

The ware is usually dried in the moulding shop or in an adjoining shed, so that it can easily be watched by the moulder.

For the burning, down-draught kilns are chiefly used, the better-class goods being protected from the flames by means of less delicate ones. Muffle kilns are sometimes used, but there is a danger that the temperature will not be high enough. Manufacturers and architects differ greatly as to the extent to which they consider architectural terra-cotta should be impermeable to water ; some insist on almost complete impermeability, whilst others are content with an impermeable face, and still others make no demands at all, and are content with a porous product. For the most durable architectural terra-cotta, a high degree of impermeability is desirable, and unless they are naturally present in sufficient proportions, the addition of fluxes to the body is indispensable. When an impervious

face on a porous body will suffice, the ware may be glazed. Much of the architectural terra-cotta in England is made of a porous fireclay body covered with a felspathic leadless glaze.

For the most durable terra-cotta, the proportion of fluxes must be such that a hard well-burned body may be obtained between 1000° and 1200° C. ; below that temperature any carbonate of lime present may not be entirely decomposed. Grey or black bodies may be obtained by burning in a very reducing atmosphere, using the methods already described (p. 333).

Coloured terra-cotta for architectural purposes may be made by using a clay which has the desired colour when burned or, when the cost is not against it, colouring oxides may be added. The only ones used are those of iron and manganese ; the former in the form of earthy ochres or certain iron ores, the latter of washed manganese ores. When, for reasons of economy, or on account of certain difficulties of manufacture, the desired colour cannot be given to the body, coloured slips must be used. The composition and application of these have already been discussed (pp. 144 and 259). To obtain a perfect agreement between the body and the slip, the latter must contain as large a proportion as possible of the body itself. The light shades, and white in particular, are difficult of application. These slips are applied by dipping or with a brush on the ware when nearly dry, or by " incrustation " (described on p. 145). During the burning, white slips must not be placed by the side of coloured bodies or slips, as there is always a certain volatilization of the coloured oxide, which would soil the former.

Architectural terra-cottas, instead of being of a uniform colour, may have different shades, by using slips of different colours, but, except for certain wares with distinctly marked different reliefs, this method of decoration gives hard tones which are not very satisfactory. It is usually better not to put different colours side by side, but only to shade the natural colour of the body. For this decoration, spraying may be used advantageously (p. 185), by using either a light slip, or some of the colouring matter diluted with water. The colour may also be applied with a brush in successive layers. This method can produce very remarkable effects, for example, by lightening the parts in relief and by darkening the sunken parts. The great disadvantage of dipping, spraying, or other superficial methods of decorating terra-cotta is that the surface soon wears away, leaving an unsightly mass ; hence it is desirable, wherever possible, to have the ware of the same colour throughout and the body sufficiently vitrified to render glazing unnecessary.

Vases, Statues, and Decorative Objects.

At the present time, vases, statues, *jardinières*, flower-pot stands, and all other terra-cotta objects used for decoration are manufactured by processes similar to those just described for architectural terra-cottas. The bodies employed are, however, finer, the clays

are almost always washed before use, and the sand or other non-plastic material to open them must be very fine, so as to give the ware a smooth and even polished appearance. The articles are made by (i) throwing and turning, or (ii) by moulding in plaster moulds. Statues must necessarily be moulded in several pieces, which are afterwards joined together. All the thicker parts, such as the head, the trunk, etc., should be hollow to facilitate drying. The joining of the parts is a delicate operation if the model is to be reproduced exactly. It very often happens that the position of certain parts, such as arms or legs, is not exactly correct—a defect which takes away a good deal from the artistic value of these articles. Moulders frequently have a bad habit of "touching up" which results in the reproductions being finished in undecided forms, with rounded contours which have lost much of the character of the original.

Such articles are dried in the moulding shop, and are burned in a muffle or in saggars.

The uniformity of tint generally demanded needs care in manufacture, and a specially regular burning. It frequently happens that, in order to give these terra-cottas a beautiful shade, they can only be burned at a very low temperature. This is not a disadvantage if the goods are kept inside buildings, but they cannot be exposed out of doors without being quickly spoilt, especially in frosty weather.

It is easier to get a uniform tint by putting a thin slip, made of the body diluted with water on the ware, or by dipping. Some manufacturers simply paint the burned ware with water-colours or with size. This process takes away all ceramic value from the ware, and is easily recognized by the colour coming off when rubbed by the finger or with a damp cloth.

Ware of many colours is easily obtained by means of coloured slips which can be thick enough to allow of different designs being made with a brush ; for example, ornaments, flowers, figures standing out in white on a coloured ground. This is the process known as barbotine painting (p. 266). Very dilute slips may also be used ; these are also put on with a brush, in successive layers, so as to form various shades. In this way more relief can be given to the model by darkening the lower parts and lightening the projections, or even by covering the various parts of the ware with different light tints. This latter method has been much used for decorating statues, vases, and bowls.

Common Pottery.

Until the Middle Ages, common pottery was almost exclusively used for all domestic purposes. Glazed ware, then faience (which may be described as a coarse earthenware with lead glaze), and, finally, fine earthenware, stoneware, and porcelain, have now completely taken the place of common pottery, except for some special purposes, and it is becoming obsolete.

The body formerly used was a fine fusible clay mixed, when necessary, with an equally fine sand. The preparation consisted in treading and kneading: machinery, except of the crudest kind, being rarely used. The body, which was always rather soft, was shaped either by hand, without moulds, or by throwing; when made, the ware was dried in the crudest manner, and it was usually burned in horizontal kilns with a single fireplace or in square or round up-draught kilns heated by wood.

The moulding of some of the more ancient objects was very remarkable on account of their size, but the burning left much to be desired, as the early potters found serious difficulties in obtaining a high temperature, and, in addition, they used very fusible and often highly calcareous clays.

At the present time, the bodies employed are the same as those used for making tiles; after being pugged into a paste the body is kept in a heap in the moulding shops so as to sour; it is re-pugged before use.

Household utensils, which are usually round, are thrown; this is sometimes made more accurate by means of a templet; the handles, spouts, and feet are put on by sticking (p. 143). Flower-pots are usually thrown, but can also be moulded on a jolley (Fig. 85), though this method needs a considerable number of moulds, or in a press. In the latter case it is wise, before taking them out of the mould, to give a certain rotary motion to the chuck, so that it will spring away from the piece, which ought to remain in the mould. With a suitable press, 600 pots of medium size can be made per hour. These wares, being always thin and relatively light, are easily dried in the moulding shop or on the shelves placed near it.

If continuous kilns are available, the burning presents no difficulty, but the goods must be protected from contact with the flames or ashes by means of coarser ware. If the output is small, a small, round, down-draught kiln may be used.

When the ware is to be exposed to the weather, it should be burned at a higher temperature than when only for indoor use, and it should be allowed to become partly vitrified.

Pottery for Water and Filters.—Pottery has been made for a very long time in all southern countries for cooling liquids. On account of its porosity, the liquid oozes out at the surface, and if the vessel is kept in a current of air, a quick evaporation takes place, which lowers the temperature 5° to 6° C. Similar pottery is also used in filters.

The body is the same as that used for ordinary ware, but special methods are used to render it more porous. If the clay used is sufficiently plastic, sand or, better, some grog or burned clay, may be added. The method described for making light bricks (p. 315) can also be used, but the combustible materials added must be reduced to a very fine powder, or the air-holes produced would be too large, and the liquid would run and not ooze out. Sometimes salt is added to the body. At the low temperature at which this pottery

is burned this salt remains undecomposed, and is dissolved out afterwards by putting the pottery into water.

The same porous body can be employed as a filter for clarifying liquids, especially water. For this purpose, white, china clay bodies, similar to porcelain bodies, have been used, but being burned at as very low temperature, are really terra-cotta. The manufacture of these wares presents no special difficulties.

Modern *filter candles* are chiefly made of kieselguhr with sufficient ball clay or china clay to bind the particles together. They are usually made into a stiff paste, which is shaped in a press, dried, and then fired. Sometimes a solid cylinder is made by expression through a pug-mill and die. This cylinder is dried and burned; afterwards it is bored and turned on a lathe to the desired shape.

Clay Tobacco Pipes.

There are two kinds of clay tobacco pipes: (*a*) Those made in a single piece used in Northern and Western Europe; and (*b*) those in

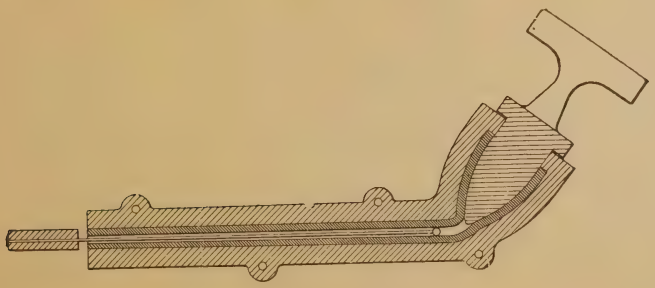


Fig. 250.—Tobacco-pipe mould.

two pieces, the bowl only being of terra-cotta—used in the countries bordering on the Danube and in the East.

For the first kind, pure clays, marls, or fireclays which contain so little iron oxide that when slightly burned they are of a white colour, are used. In some factories the colour of the iron is discharged by adding a suitable quantity of chalk so as to produce an artificial marl. These clays are made into a paste, usually by hand, this being carefully done so as to make a very homogeneous mass.

Tobacco pipes are moulded by hand, a roll of body being made and a lump of body being attached to one end. By means of a wire terminating in a small ball, a hole is pierced down the middle of the roll, then, when this rough model is stiffened, the whole is placed in a copper or white metal mould in two parts (Fig. 250), which are pressed together by a screw. To form the bowl a plug is put in with a rotary motion, as shown in Fig. 250. After the plug has been taken out, the piercing of the communication between the bowl and the pipe must be finished by means of a wire put in through the bowl; the pipe is then taken out of the mould and laid aside to

dry. This moulding, which is very simple, is usually done by women or children, who become very quick at it. Any ornamentation desired can be placed in the mould, provided it will prove no hindrance to the pipe being taken out. If such is not the case it must be stuck on afterwards. Superior pipes are afterwards polished externally.

Pipes must be dried very slowly on account of the plasticity of the body, but there are no special difficulties connected with drying.

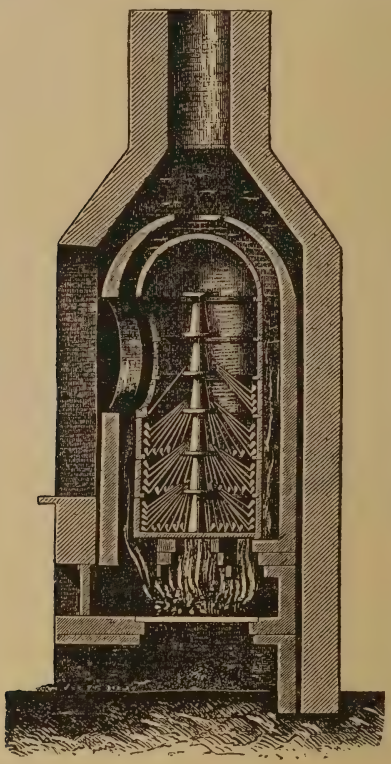


Fig. 251.—Tobacco-pipe kiln.

The pipes are burned either in small square or round up-draught kilns in saggars, or in muffle kilns. Fig. 251 shows an arrangement of saggars with the special method of setting the pipes in them. When only the bowl is made of clay, either a white-burning body may be used or a plastic ferruginous clay, similar to that used for making red paving tiles. When necessary, it is mixed with grog made by heating the same clay. The bowls may be shaped by throwing on wheels, and are finished by turning. Alternatively, the bowls may be made by moulding or by casting (p. 141). The

part for holding the stem is then stuck on, as it has been turned separately. The bowls are burned in saggars, but on account of the simple shape of the pieces, do not need a special method of setting.

The finishing operations may include any or all of the following :—

(i) Waxing the mouthpiece to prevent it from adhering to the lips.

(ii) Decorating the bowl by any of the methods used for other kinds of pottery.

(iii) Glazing the bowl—chiefly adopted in Germany.

On account of the dexterity required for making tobacco pipes, which can only be acquired by a long apprenticeship, their manufacture is localized in places where there is a population accustomed from childhood to this work. The most important centres of this manufacture in England are London, Broseley, and North Derbyshire, but the industry is now very small, wooden pipes having almost wholly replaced those of clay.

Polished or Lustre Ware.[1]

Lustre ware is chiefly of historical interest. It has a coloured body with a slight gloss or lustre, and was manufactured by the Egyptians, the Greeks, and the Romans from the sixth century before our era till towards the year 300, at which time it fell completely into oblivion and was only revived in the course of the nineteenth century.

Various clays were used, the body sometimes being moderately plastic and ferrugino-calcareous (Greeks and Romans), and sometimes decidedly silicious (Egyptians). Some of the ware was shaped by throwing ; other pieces appear to have been moulded, but all of it appears to have been polished either before or after burning.

The cause or composition of the lustres used for covering these wares remained a secret for a long time, and even now the problem cannot be considered to be entirely solved. It was at one time attributed to the mode of burning, it being assumed that saline matter in the clay, or purposely added, accumulated on the surface during drying, and was fused during the burning, forming an extremely thin coating of glaze. Some of the colours produced appear to be wholly due to the burning, which was usually at a low temperature, and under various conditions of oxidation and reduction, so that the ware may be of almost any colour—from yellow or grey to brick red. Moreover, the Greeks understood slips, which allowed them to make white, yellow, or deep red ornament by means of mixtures of white clay and ochres. They frequently used to polish the ware before it was burned, an operation which gives the surfaces

[1] This ware must not be confused with the pottery having a metallic sheen of broken lustrous colours.

a particular brightness after burning. These methods of decoration, added to the action of fusible ashes from the wood used as fuel, have often led people to think that some of their wares were covered over with a glaze.

Certain red, black, or grey parts in the Greek ware and the greenish parts in the Egyptian ware, appear to have been decorated by means of a thin layer of a somewhat vitrifiable material, probably put on with a brush. According to Brongniart's analysis, this lustre is an alkaline silicate, the very thin layer of which, when burning, combines with the body. When it was red it contained iron oxide, from which the colour was added to the body. The green shades of Egyptian pottery were produced by copper oxide. The analysis of black lustre has only shown iron oxide, sometimes mixed with a little manganese oxide in a proportion quite insufficient to produce a black ; this lustre when heated in an oxidizing atmosphere becomes red, which shows that the black must be attributed only to the ware being burned in a decidedly reducing fire. In wares where the background is black, while the places where the ornaments come off are red, either spaces have been left or the black lustre has been scraped off afterwards.

On account of the soft nature of the body, it could be polished, carved, and even painted or varnished, and the view chiefly held at present is that these wares were polished before or after burning. In some ware there is evidence of an applied coating, but it is very difficult to ascertain its composition on account of its uniting with the body, which prevents it from being removed and analysed separately. According to Salvetat, black lustre consists of 15 per cent of sand, 25 per cent of lime and alkalies, furnished either by the ashes or by volcanic products, and 60 per cent of a ferruginous earth. If this is correct, it can only produce black ware when burned in a strongly reducing fire.

Properties of Bricks, Tiles, and Terra-cotta.

Causes of Disaggregation and the Remedies.—All kinds of terra-cotta, when well made, should be able to resist indefinitely the action of the weather, and the mechanical effects to which they are subjected in building.

The probable causes of disaggregation are :—

(1) External physical causes, such as damp, vegetation, ice, saline atmosphere, sudden changes in temperature.

(2) Mechanical causes, such as external pressure or blows.

(3) Internal chemical causes, such as the presence of lime, magnesia, or soluble salts in the terra-cotta.

When terra-cottas are too friable, prolonged damp or frequent rain is sufficient to crumble them away. If porous, they may also be covered with vegetation, the roots of which will help to destroy them. Both these defects arise from the use of bodies which are too sandy or insufficiently burned.

Frost has a more powerful and more dangerous action. In consequence of a lowering of the temperature, any water absorbed by the terra-cotta solidifies in the interior of the pores. The increase in volume of ice at the moment of freezing creates internal pressure which may crack the terra-cotta; it then gradually crumbles away. The saline atmosphere of the seaside exerts a similar action; this must be attributed to the formation of salt crystals inside the pores, which act in the same way as ice does, but often more powerfully. It is not the intensity of the cold that is to be feared, but a cold of only 2° or 3° C. below zero, following quickly on a rainy season, because then the water contained in the pores of the terra-cotta has not had time to evaporate. Nothing need be feared from cold, however intense, following a dry season. On the other hand, snow may very effectually protect terra-cotta. This explains why some terra-cottas, which perfectly resist severe climates, can be crumbled away in temperate, but damp, countries.

In order that a terra-cotta may resist the action of frost, it is necessary :—

(1) That the walls of the pores should have a sufficient tenacity to bear the pressure of ice; this can be obtained by using sufficiently plastic bodies, and especially by burning them at a high temperature.

(2) That the pores should be uniformly spread over the whole mass, that is to say, the latter should be homogeneous without planes of cleavage, or of thin layers. This condition is naturally fulfilled when a very homogeneous body is shaped by hand either in a mould or on a wheel; the processes of expression and pressing, on the contrary, always tend to give a lamellar structure to the body, so that the water—instead of being enclosed in a number of small cells, the tensions in which balance each other—forms a sheet between the different leaves, and on being changed into ice exerts a pressure which, being unbalanced, may cause these layers to crack. This lamellar structure is more noticeable when the moulding is done with a stiff body, as, the plasticity being less, the layers cannot join together. In pressing a dry body, this primal cause of lamination is decidedly aggravated by the air enclosed in the mass at the time of pressure, layers being formed which destroy the cohesion between the different particles.

The best methods for obtaining terra-cotta absolutely impervious to frost are :—

(1) A thorough mixing of the raw materials in such a way that lean and rich parts cannot be found in the body. In a badly mixed body these would slide on one another when being moulded, without mixing together, and would cause a lamellar structure.

(2) Moulding with a body of a consistency as nearly as possible like that used for modelling by hand.

(3) The employment of processes and machines which reduce to a minimum the lamellar structure of the body.

(4) When the last two conditions cannot be fulfilled, it is necessary to raise the temperature in the burning sufficiently to cause

the fluxes in the mass to begin to vitrify. If this cannot be done without causing the ware to lose its shape, the only alternative is to modify the composition of the body.

In a general way, moulding by expression, or by presses with stiff or dry bodies, can only produce ware impervious to frost on condition that it is burned at a temperature causing incipient vitrification.

The chief mechanical causes which may account for the breaking of bricks, tiles and other terra-cotta are the following :—

The weight the *bricks* have to bear may crush them. Except under certain exceptional circumstances, the resistance of bricks is far greater than is necessary, the strength of the brickwork being far less than that of the bricks, as it is limited by the strength of the mortar used in the joints. Only bricks made of very sandy bodies and under-fired can be crushed under ordinary circumstances. If very resistant bricks are wanted, plastic bodies must be moulded at a comparatively stiff consistency without re-pressing, and burned at as high a temperature as possible. Except in special cases, it is unnecessary to obtain great resistance at the expense of other qualities.

The greatest strain *tiles* have to bear is the weight of a man moving about on a roof. This resembles a weight of 2 cwt. placed in the middle of them, or needed to break them by bending them when they are overlapping. As their thickness can be modified, it is always possible to make tiles sufficiently resistant.

It is advisable to test *paving tiles* for wear, and *pipes* for their resistance to an internal hydraulic pressure. In these two cases the greatest resistance is obtained with close and well-burned plastic bodies.

To resist the shocks which bricks, tiles, and terra-cotta receive during transport, they should be made of a plastic paste, which is well burned without a serious amount of vitrification, because when they have attained to the highest point of resistance by a suitable amount of heating, a further increase in temperature makes terra-cotta more brittle.

Terra-cotta may crumble when it contains lime or caustic magnesia, which, when wetted, increases in volume and acts like frost. This may be avoided by a better preparation of the body ; but if the expense caused by a more careful working of the body is too great, relatively to the small value of the ware produced, the harmful action of the lime may be lessened by dipping the goods in water as they come out of the kiln. For this purpose the apparatus shown in Fig. 252 may be used ; it consists of an underground tank full of water, into which are lowered barrows loaded with the goods.

When a body contains a large proportion of soluble salts these may be dissolved by rain or damp and accumulate as crystals in the pores on the surface, thus acting in the same way as the saline atmosphere of the seaside. This action is, however, rare, and usually the efflorescence of the soluble salts only discolours the surface and

makes the parts above them scale off. This defect may be avoided by washing the articles, or by burning them at a temperature sufficiently high to cause the conversion of these salts into insoluble compounds. The processes for chemically destroying these bodies which can sometimes be employed have been described on page 90.

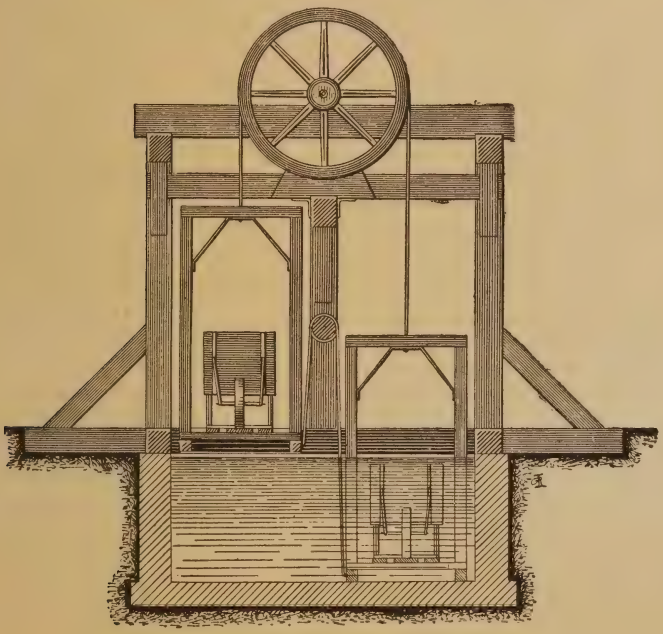


Fig. 252.—Arrangement for dipping bricks.

The methods of testing terra-cotta have been the subjects of much discussion, and some countries have definite standard tests to which all bricks and roofing tiles must conform.

Tests should always be made on the whole article, where possible, as tests of small portions are often seriously misleading.

Physical Tests.—(1) *Observation of the structure or homogeneity* should consist of the examination of a fracture, either by naked eye or by a magnifying glass, special attention being paid to :—

(*a*) The appearance of the fracture, whether granulated, rough or smooth, or with a conchoidal surface.

(*b*) The sizes of the grains, marking according to the classification adopted for natural stones [1] whether the grains are fine, medium, or coarse, and uniform or of different sizes.

[1] Very fine grains (0·2 to 0·4 millimetre), fine grains (0·3 to 0·8 millimetre), rather fine grains (0·5 to 1·2 millimetres), medium grains (1 to 2·5 millimetres), slightly coarse grains (2 to 4 millimetres), coarse grains (3 to 7 millimetres), very coarse grains (5 millimetres and over).

(*c*) The homogeneity, by observing whether the mass is entirely, moderately, or slightly homogeneous, whether there are any planes of cleavage or scaling, and whether these are numerous and pronounced.

(2) *The specific gravity* [1] of a material may be determined on the powder produced from pieces ground up until they will pass through a sieve of seventy-five meshes per running inch. The powder should be dried at a temperature of about 110° C., and the determination of the specific gravity should be by means of a "bottle," in such a way as to obtain the first decimal exactly, and the second approximately. The liquid used should be benzine or paraffin, which penetrates the pores more easily than water. The temperature should remain constant during the whole time of the operation, and ought not to be above 15° C.

(3) *Apparent density* should be determined on whole samples after being dried at a temperature of 30° to 40° C. When the samples are of a regular geometrical form, allowing the volume to be determined by measurement, an ordinary rule is used with a scale reading to one-hundredth of an inch or one-tenth millimetre; the weight should be determined by means of a delicate balance.

When the samples are irregular in form, or have any receding angles, the volume should be determined by first covering the surface with varnish or a thin layer of melted tallow to prevent any water getting into the pores, then suspending the sample by a thread from the arm of a delicate balance and weighing twice—first in air and then immersed in water. The difference (in grammes) between the two weighings will give the volume of the sample (in cubic centimetres.)

(4) *Absolute porosity* should be calculated from the difference between the specific gravity and the apparent density.

(5) *Relative porosity, or the weight of water absorbed in a given time*, should be determined on at least three separate samples, previously dried, either in the open air or in an oven, at a temperature of 100° to 110° C. It is advisable to work as much as possible with whole samples, and not with broken pieces.

After they have been dried, the samples are weighed separately and are then put into water up to half their height for twelve hours, and are then completely immersed for twelve hours, thirty-six hours, seven days, or twenty-eight days.[2]

If the samples contain a decided proportion of lime, magnesia, or soluble salts, it would be wise to repeat the experiment once or twice on the same samples.

[1] The determination of the specific gravity is of no interest from the point of view of the quality of bricks, tiles, or terra-cotta; it is only used for calculating the absolute porosity.

[2] In the case when the time of immersion passes forty-eight hours, if it is desired to shorten the length of experiment, a pneumatic bell (vacuum chamber) can be used as air escapes from the sample, and water enters more readily when it is under reduced pressure.

The quantity of water absorbed, or the relative porosity, should always be calculated by volume, but the percentage of water by weight should always be also noted. The difference is important, as the percentage by volume gives a direct measurement of the volume of the pores. If the sample contains any sealed pores they will not be revealed by this method, which only indicates the pores into which water can enter.

Roofing tiles may be tested separately as described, but it is also an advantage to fit several tiles in a frame in the same position as they would be in a roof, and to determine the increase in weight when they are exposed to an artificial rain of a definite intensity for a given time.

(6) *Permeability.*—This test should be made with at least three whole tiles previously immersed for forty-eight hours, as described in paragraph (5). In the middle of the upper face of each tile, a glass tube, of about $1\frac{1}{4}$ in. interior diameter and about 12 in. high, should be cemented and filled with water; the water which can pass through each tile is collected in a vessel placed underneath, and is measured after twenty-four hours or more.

(7) *Tests for the resistance to frost* ought as much as possible to be carried on with whole goods, though they could be made on broken pieces if the cut or broken parts of the tiles were protected by varnish or a thin layer of tallow to prevent the water from penetrating during the immersion, except through those faces of the samples which are usually exposed to the weather.

The tests for a normal resistance to frost comprise :—

(*a*) The examination of the samples with the aid of a magnifying glass to see whether cracks or splits are caused in those samples submitted to the action of successive freezings and thawings repeated up to twenty-five times.

(*b*) The determination of the loss of weight in the frozen samples.

In carrying out these tests the following details must be observed :—

(*a*) Distilled water must be used for the immersion, at a temperature of $+ 15°$ to $+ 20°$ C., or if distilled water cannot be had, then drinking water which contains so little soluble salts that they may be neglected.

(*b*) The samples should be exposed to a temperature of $- 15°$ to $- 20°$ C.

(*c*) The length of exposure to the cold should be twenty-four hours.

(*d*) The thawing should be done by the complete immersion of each sample, in distilled or drinking water at a temperature of $+ 15°$ to $+ 20°$ C. With dried samples, after being frozen for twenty-four hours the thawing is accomplished in damp air and not in water. In the interval which separates the successive thawings and freezings, the samples are kept in closed cases, to prevent too large a loss of the water absorbed. Care is to be taken before submitting them again to the action of the cold to plunge them for some moments into water, so as to keep them during the whole period

of the test at the same degree of saturation as they had at the commencement of the experiment.

For these tests at least three samples should be used.

Mechanical Tests.—*Resistance to being broken by crushing* should be measured on pieces as nearly cubical in form as possible, obtained with ordinary bricks, for example, by putting two half-bricks on another and joining them together with a thin layer of Portland cement paste; the surfaces to be compressed should be made exactly parallel by a covering of the same body, and to ensure the pressure being uniformly distributed a piece of thick cardboard should be placed above and another below the sample.

The tests for resistance to crushing may be made by means of lever apparatus or by hydraulic presses, the latter being preferable.

The dimensions of the bearing surfaces should be shown in the report of the test, at the same time as the resistance per square inch of the carrying surface.

The test should be made on at least three samples, and the mean of the results calculated.

Resistance to breaking by bending should be measured on a whole tile placed on two knife-edges 8 in. apart, and loaded in the middle continuously until it breaks; the total weight which causes the breaking of each test-piece being noted. If preferred, the article may be tested with a distance between the two edges on which they rest, equal to that between the supports which they would have in use.

When testing tiles or other goods which have not a rectilineal profile, little transverse horizontal bars of pure Portland cement should be put at right angles to the supports and to the medial knife-edge for the purpose of levelling the undulations and of making the pressure uniform over the whole width of the sample. One of these supports should be placed at the point where, in the roof, the tile ought to lean on the roof-ledge, and the other on the place where it rests on the lower tile.

The test should also be made on tiles soaked with water, the amount of saturation being noted.

Resistance to being worn by rubbing may be determined by measuring the extent to which the samples are worn when, under a given load, they are subject to the rubbing of a normal sand spread evenly on a circular cast-iron plate, which is rotated at a given speed. For this, the samples should be $2\frac{1}{2}$ by $1\frac{1}{2}$ in. base, and a height varying from 4 to $4\frac{3}{4}$ in.; they should be put two and two on all sides of the axis and on the same diameter of the mill, in such a way that their centres will be on a circumference of 10 in. radius, the small dimension being placed perpendicularly to the radius. The total load on the plane of rubbing should be kept constant at 250 grammes, or more, per square centimetre.

The sand used should be obtained by sifting Fontainebleau sand or its equivalent, and using the portion passing through a No. 50 sieve, and entirely retained on a No. 200 sieve.

The quantity of sand to be spread on the mill should be 1 litre ($1\frac{3}{4}$ pints) per test piece and per 1000 turns of the mill. The apparatus should be turned at the rate of 1000 turns per half-hour, and the sample subjected to 4000 turns of the mill. The diminution in height of the sample should be measured and the loss in weight which it has sustained determined. The same particulars should be noted in the course of the test after 1000, 2000, and 3000 turns.

The sample may be turned over from end to end after 2000 turns of the mill, so as to compare the results obtained on the lower and upper faces.

In America, the standard test for abrasion consists in placing the bricks in a kind of pebble-mill called a "rattler" and noting the loss in weight.

Resistance to Breaking by a Blow.—No rules have been fixed for this test.

Resistance to breaking pipes by internal pressure should be tested either by the help of a force pump, or by means of a hydraulic accumulator. The pressure required to cause breakage is expressed in kilogrammes per square centimetre (or pounds per square inch) of surface exposed to the pressure.

The pipes to be tested should be exactly filled with water, the pressure being gradually and not suddenly applied. The gauge should show, directly, the pressure exerted in the pipe itself. The test may be made either on a single pipe or on several pipes joined together, the joints closing the extremities of the pipes being arranged in such a way that they will not leak, and made in such a manner that the tightening of them will not lead to a premature bursting of the pieces subjected to the test.

Chemical Tests.—Most of the tests for impurities require considerable knowledge and experience of chemical analysis, and should, therefore, be made by a qualified chemist.

The determination of the soluble salts should be made on five samples, which are powdered so as to make them pass entirely through a sieve of 75 meshes per running inch. Twenty grammes of the powder thus obtained from each sample is boiled for an hour in ten times its volume of distilled water, replacing the water that has evaporated. The total volume is diluted to a convenient amount (250 c.c.), an aliquot part of the liquid is filtered, evaporated to dryness, and the residue of soluble salts thus obtained is weighed.

In many instances, the quantity of soluble salts is so small that the foregoing test will scarcely produce a result. It is then better to support the sample on two glass rods laid across a glass or porcelain dish, and to allow water to drop on the sample. If the quantity of water so added is properly controlled, the soluble salts will accumulate on the surface of the sample and will be seen after it has been allowed to dry. From the amount of scum or efflorescence so produced a fair idea of the quantity of soluble salts present may be obtained.

CHAPTER XI.

REFRACTORY MATERIALS.

Refractory materials are distinguished from others made of clay by their great resistance to heat, for even at the temperature used for burning hard porcelain they do not become vitrified. They are of a dull yellowish-white or slightly greyish colour, except one variety which is black. Chemically, they may be divided as follows :—

Acid products, formed of pure alumino-silicic acid (clay), of a mixture of alumina and silica, or of nearly pure silica ; their acid properties being in proportion to the silica.

Basic products containing a large proportion of lime or magnesia, or a mixture of these bases.

Neutral products : (i) formed of alumino-silicates which are more aluminous than pure clay, the alumina acting as a base to acids, or as an acid to certain bases such as lime ; (ii) neutral substances, as chromic oxide, graphite, zirconia, etc.

Reducing or carburetting products containing carbon.

Oxidizing or decarburetting products formed of iron ores, and at present only used for some furnaces and not as clay products.

Pure clay produces slightly acid goods because, when sufficiently strong bases are present, it, being a bi-silicate, may be changed into a mono-silicate, giving up one equivalent of silica, at high temperatures. By adding more silica to the clay, the acid properties are increased, and by adding alumina they are diminished, or are completely neutralized ; the composition of the ware then corresponds to that of aluminium mono-silicate. On the other hand, by adding a sufficiently large proportion of lime or magnesia, ware of a basic reaction is obtained, and by adding carbon to clay a dark, carbonized ware can be produced.

Silica, lime, or magnesia may be taken as a starting-point, and goods made containing as high a proportion as possible of any one of these substances, only the quantity of agglomerant strictly necessary to allow of their manufacture being used. In this case, the agglomerant may be clay or any other material answering the same purpose, though goods so obtained are not " pottery."

The following classification is convenient :—

(1) *Argillaceous fireclay goods*, more or less acid, having fireclay (or, more rarely, china clay) as the chief constituent.

(2) *Aluminous fireclay goods*, slightly acid or neutral, made of a mixture of clay and alumina, or of compounds relatively rich in alumina.

(3) *Carboniferous fireclay goods*, in which there is a large proportion of free carbon.

(4) *Silicious goods*, strongly acid, composed almost exclusively of silica.

(5) *Basic goods*, containing a preponderating proportion of lime or magnesia, or a mixture of these two bases.

Iron chromate is sometimes employed as a refractory material which resists acids as well as bases, and also a very high temperature.

1. *Argillaceous* (*Fireclay*) *Goods.*

Shapes, Dimensions, and Properties.—The manufacture of argillaceous fireclay goods in special factories only dates from the beginning of the nineteenth century. By accurate chemical analysis it is often possible to distinguish fireclays from other clays, and to decide the composition they must have to be able to resist high temperatures and the attacks of the materials with which they come in contact in the kilns. A great advance was also made in heat resistance when the clays were " opened " by means of fireclay grog (p. 40) instead of sand, as in ordinary bricks. The use of grog was known in the Middle Ages, but it is only since the beginning of the nineteenth century that it has been used methodically.

Fig. 253 shows some common applications of fireclay goods, but the shapes may be infinitely varied. Plain bricks are usually of the shape and dimensions of building bricks : (I) in France, $8\frac{2}{3} \times 4\frac{1}{3} \times 2\frac{1}{3}$ in. ; in England, $9\frac{1}{2} \times 4\frac{1}{2} \times 2\frac{1}{2}$ in. ; and in Germany, $9\frac{3}{4} \times 5 \times 2\frac{1}{2}$ in. In the usual way, arch bricks (II) and wedged bricks (III) are made for building domes and arches. Other special and complicated patterns (IV and V) can be easily made when required. When the pieces are much larger than ordinary bricks they are called *blocks ;* the latter are better for building kilns, as they lessen the number of joints, which are always a weak place in masonry. A length and width of 24 in. by a thickness of $15\frac{3}{4}$ in. should not be exceeded, as above that the blocks are unwieldy, and there is a risk of their not being burned throughout.

Slabs (VI) (or *quarries*) are made $1\frac{1}{2}$ to 4 in. thick with a length of 39 in. and a width of 20 to 24 in. ; they may be flat or curved.

In some cases, hollow bricks are made, as tubular bricks for recuperators, gas burners (VII), channels (VIII), etc.

Muffles, ordinary crucibles (IX), the height of which varies from 2 to 24 in. ; glass-house pots (large crucibles for melting glass), ordinary retorts (X), measuring up to 28 in. wide by 20 in. high and more than 40 in. long ; gas retorts (XI) being similar in width and height, but 6 ft. long ; laboratory furnaces, etc., are also made of fireclay.

All refractory goods ought, as far as possible, to fulfil the following conditions :—

(1) They must resist, without warping, the highest temperature to which they are likely to be subjected. This resistance to heat depends mainly on their chemical composition and partly on their physical texture.

(2) They should bear variations of temperature without cracking or breaking, though what is to be feared are the differences of temperature between the parts of the same article, and these are the more difficult to prevent in proportion as the heating or cooling is

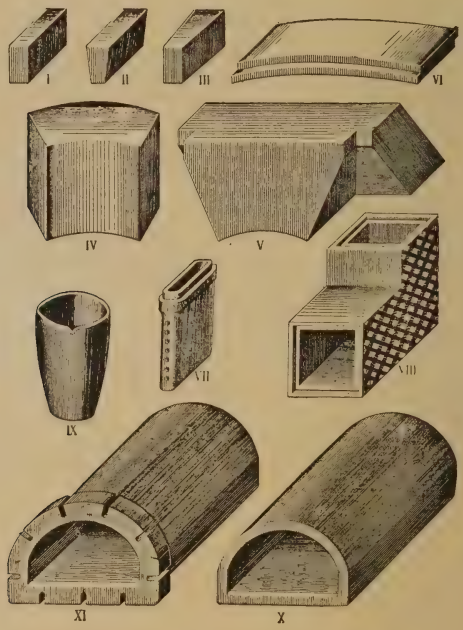


Fig. 253.—Articles made of fireclay.

more rapid. Thus, a thick crucible might break under some conditions of heating which a thinner crucible would have resisted. The more open the texture of the ware and the less it is burned, the more quickly is the temperature of the mass equalized, and the less liable will it be to crack or break. In dense pastes, which are partially vitrified, the thermal conductibility is less, it is more difficult to keep the temperature equal, and the result is that the goods expand irregularly, causing unequal tensions which the mass cannot resist and so breaks or cracks.

(3) Fireclay goods ought also to resist the action of the different materials with which they come in contact in use. Those which

principally exert a harmful influence are the ash of the fuel, the contents of the furnace, or the gases which escape from them. Fireclay goods are easily attacked by all substances which unite with silica to form silicates, viz. alkaline bases, alkaline earths, and certain metallic oxides. At low temperatures an opposite reaction may be produced ; the acid displacing the silica from its combination with the alumina and other bases in the body. Fireclay goods are attacked more vigorously the more porous they are, the less so the denser the ware, or the higher temperature at which they have been burned.

As the two preceding conditions are contradictory, it is impossible to make ware that can, at the same time, bear a rapid heating and resist the action of alkaline ashes or the corrosive action of melted glass or slag. It is necessary to compromise in each case, according to the importance or amount of attacking agent. Thus, if a firebrick is made to resist slag it may or may not resist flue-dust or furnace gases.

If fireclay goods are heated to a higher temperature than that attained during the burning they will usually shrink, and this may cause cracks or dislocation of the masonry. If the bodies contain a considerable proportion of quartz, the opposite may occur, as quartz expands ; under great and prolonged heat, its density changes from 2·7 to 2·3.

Resistance of Fireclays to High Temperatures.—In the chapter on burning, the effect of the different materials in the body on its fusibility, as well as the modifications of the different properties of the body caused by burning were explained.

The chemical composition of fireclays plays a more important part than in most other kinds of ware, as very small proportions of alkalies, lime, and magnesia greatly reduce the refractoriness. Fireclays are composed of pure clay, silica, and fluxes, the latter being always in small proportion, but the amount of silica may be as high as 50 per cent. This term " fireclays " often includes not only clays properly so called, but also the primary clays, providing they are sufficiently free from alkalies and iron to be used in the manufacture of fireclay goods, and even ganister and other forms of almost pure silica ! This broad use of the word is often misleading.

Alumino-silicic acid (" pure clay ") melts at the temperature corresponding to Seger cone, No. 36, which is about that for fusing platinum (1775° C.). The fusion point is lower when silica is added to the pure clay until the mixture contains one equivalent of alumina to 17 of silica (90·84 per cent of silica and 9·16 per cent of alumina). From that point, if the amount of silica is further increased, the body becomes more refractory again, until when it contains only pure silica (rock crystal) it can resist a temperature corresponding to cone 35, and equivalent to the " fusing point " of pure clay containing a trace of alkalies. If, however, alumina is added to pure clay, the mixture becomes more and more refractory, until pure alumina is reached, which resists a temperature above any of the

preceding ones, and does not show any trace of vitrification at the temperature of fusing platinum.

Fig. 254 represents the foregoing statements in a graphic form. The temperatures are expressed in Seger cones, the figures below the horizontal base showing the percentage of silica and alumina in the mixture.

The vertical line corresponding to 46 per cent of alumina shows that pure clay has a refractoriness corresponding to cone 36, and the short vertical line corresponding to 9 per cent of alumina, shows that the refractoriness of the least refractory mixture is the same as that of Seger cone 29.

According to Richter, the action of fluxes as regards fusibility is apparently, but not decisively, in proportion to their equivalence ; that is to say, that 20 parts of magnesia act the same as 28 of lime,

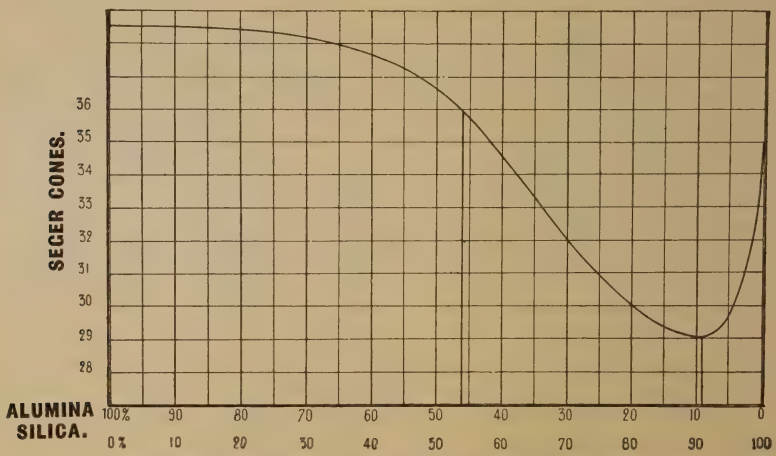


Fig. 254.—Fusibility of mixtures of alumina and silica.

31 of soda, 36 of ferrous oxide, and 47 of potash. This rule seems also to apply to the peroxide of iron (ferric oxide), which appears to be as infusible as alumina, and the equivalent of which is 80. Unfortunately, Richter's rule is not very reliable, nor are any others which attempt to connect the refractoriness and composition of a fireclay, as so much depends on the size of the particles and other physical properties, as well as the gases in the kiln or furnace. Various reactions may also occur ; thus at high temperatures iron peroxide (Fe_2O_3) is always partially changed into the protoxide (FeO).

It is well known that these relative fusibilities of the different fluxes can only be accurate at high temperatures, i.e. at the moment when the whole mass of the body being molten or at any rate semi-molten, so that definite compounds may be formed. No rule can be accurate at a lower temperature, because then the fluxes

may be mixed up with other compounds which are still unfused at that temperature. This frequently happens with alkaline fluxes, which often occur in the bodies in the form of felspar, and can only act when that rock begins to vitrify. Lime occurring as calcium sulphate behaves similarly.

Bischof tried to define the fusibility of fireclays numerically, taking as a basis the proportion of fluxes present, expressed according to their equivalents, and comparing it with the proportion of silica and alumina. In this way he represented the composition of the clays by a formula in the form—

$$a\mathrm{Al_2O_3} + b\mathrm{SiO_2} + \mathrm{RO}.$$

RO is taken as the unit representing the fluxes, a and b indicating the amount of alumina and silica in proportion to those fluxes. He suggested that the coefficient of fusibility is equal to $\frac{a^2}{b}$, the highest number being supposed to indicate the most refractory clay. This theory seems to correspond fairly well with direct pyrometric results for certain clays, but as it rests on a chemical analysis, it is far less reliable than a direct fusing test in which the clay is compared with Seger's cones. This theory is only mentioned because it has numerous partisans, especially in Germany. In a similar theory by Th. Ludwig a chart is used on which the positions of the various Seger cones are plotted in relation to the factors x and y in the formula

$$x\mathrm{RO} + \mathrm{Al_2O_3} + y\mathrm{SiO_2}.$$

This chart, whilst far more accurate than Bischof's formula, is only applicable to some fireclays, because no method of calculation can show reliably the fusing point of any clay from its analysis, though Ludwig's work, like Bischof's, is of great interest.

Composition and Preparation of the Body.—Fireproof bodies are usually composed solely of fireclays or china clays (kaolins) with the addition, when necessary, of some opening material such as grog or free silica. For very plastic clays, the proportion of opening material may be as high as two parts by weight to one part of clay, while it may not be possible to add any non-plastic material to very silicious clays.

The use of silica as an opening agent modifies the chemical composition and reduces the temperature which the material can resist; it does not allow the grains to be as coarse as is desirable, and makes the body liable to swell, and even crumble, in consequence of the expansion of the silica. Hence for all best fireclay goods only grog made of fireclay or of calcined alumina should be used as a non-plastic material. Fireclays which are decidedly silicious are only pure clays thinned with sand, and naturally present all the disadvantages just pointed out; they can never be used to make fireclay goods of the highest quality, but are, nevertheless, very useful for

many purposes (such as the crowns of furnaces) where a non-shrinking material is important.

The largest part of the grog used in the manufacturé of fireproof goods is furnished by the rubbish of fireclay works, viz., bricks, crucibles, retorts, saggars, etc. This rubbish is ground and then sifted to obtain grains of various sizes. If sufficient of this grog cannot be obtained, it may be made by forming natural clay into balls and burning these in the same kilns as are used for ware. It is seldom that special kilns are used for this purpose.

Fireclay is usually dug a long time before it is needed. It is allowed to " weather " as long as possible to break it down and to oxidize any iron pyrites. The well-weathered material is then dried in the open air or in special kilns, and finally ground to powder.

This clay and the grog are mixed in bulk in a pug-mill and adding the desired proportion of water to them. In well-arranged factories the clay powder and the grogs of different coarseness are stored in hoppers, placed in the upper part of the buildings, from which they naturally run down into the pug-mill, which may be either vertical or horizontal. The latter is usually preferred because it makes the body closer with fewer air-bubbles in it. A good method of preparation consists in first using an open pug-mill or mixer, as shown in Fig. 28, and then passing the body through a second pug-mill, which makes the body into large blocks. These are kept for some time in a damp place to *sour* before being used for moulding.

In a general way, it is best to use as infusible a clay as possible ; but in some cases it is advisable to use clays which, at the temperature at which they are burned, show signs of beginning to soften, as they then make the body closer and better able to resist the action of the materials with which it comes in contact in the kilns.

To manufacture goods that will resist rapid changes of temperature, as much grog as possible must be incorporated with the clay, the former being of a fairly coarse grain. The dimensions of these grains depend largely on those of the object to be made. For thick blocks, they may be as much as $\frac{1}{4}$ in. diameter, but can be reduced to $\frac{1}{16}$ in. for thin ware. By employing coarse and fine grains at the same time, the smaller grains enter between the larger ones and allow a larger proportion of water to be mixed with the clay.

Moulding.—Fireclay goods are made by moulding by hand or by " drawing." If the former, the body employed must be of a decidedly stiffer consistency than that used for moulding ordinary bricks, because it is essential to obtain more compact goods. This consistency necessitates the body being tamped or beaten inside the mould, instead of being made in the manner described in the preceding chapter. The moulds must be more solidly made. They are of wood, the joining being done with wooden corsers or bolts. It is sometimes necessary to strengthen very large moulds with iron bands. This hand-moulding, to be successful, needs great technical skill, care and regular work.

Fire-bricks are made in moulds similar to those used for building

bricks, but the output is much less, because of the stiffness of the paste. For larger pieces and blocks, the moulds are filled by throwing the pieces in to form horizontal layers. When the shapes are complicated, or when there are empty parts, a rough model is moulded, and afterwards carved. Some round pieces may be "thrown," but this operation is not usually very easy, because of the granulated texture of the body.

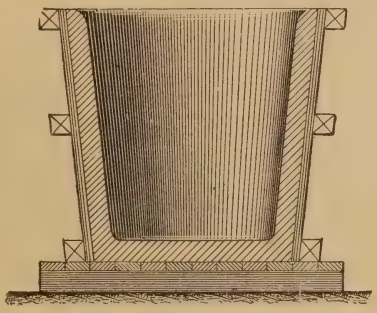


Fig. 255.—Moulding a glass pot.

For hollow pieces of a large size, such as pots for glass-making or gas-retorts, the bottom is first made on a plank of wood, either by putting lumps of clay paste side by side, or by sticking together slabs cut off from the blocks of body which issue from the pug-mill. The bottom is roughed out first with a thickness decidedly greater than is needed, then it is reduced by pressing it in such a way as to make the body spread towards the edges. Round this bottom is then placed the mould to be used for the walls, and on this is put more body, beaten out and suitably joined together. Fig. 255 shows the moulding, by this method, of a pot for melting glass, the mould being in two pieces, joined together by bolts or hooks, so that it may be removed without disturbing the contents. In Fig. 256 is shown the making of a gas retort; the mould being in several pieces joined by pins, which are put on one another as the moulding advances. The inside shape is obtained by smoothing the surface with the hand, and passing a template over it, or by measuring the thickness of the body by means of a pair of calipers.

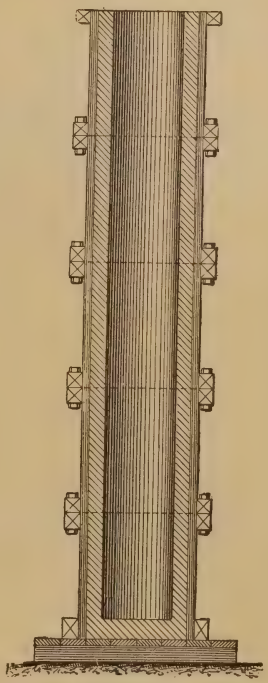


Fig. 256.—Moulding a gas retort.

Plain fire-bricks can also be made by the wire-cut process previously described. By inclining the wires of the cutting board bricks with sloping sides or wedge-shaped bricks can be made.

For hollow goods of a rectangular section, when made in moderate quantities, piston propellers worked by hand are generally used. But crucibles or retorts, with a cylindrical or a prismatic section, and

drainage pipes of large diameter, are expressed from machines with vertical piston propellers (Fig. 292). The bottoms or ends are always added and joined by hand.

Some goods, e.g. saggars, are made by first moulding slabs of

Fig. 257.—Saggar-making machine.

the body by hand, on a table dusted over with grog, on which are fixed four rules, the thickness of which is equal to that of the slab. The body should be firm enough to be roughly shaped by striking it with a wooden bat. It is then smoothed, lifted, and rolled round a wooden mould, the inside of which is the shape of the saggar. To

add the bottom, the mould is placed on another slab of body, and the ring and bottom are joined together by hand. To take the mould out of the article it is sufficient to strike the body, which lengthens slightly and becomes detached from the mould, which is then drawn off vertically. The mould should be removed at once or the clay will shrink on it and crack.

When a machine replaces handwork, the slabs of body are placed in the interior of the mould or press-box, which corresponds to the outside of the product; then a piston is pushed in, and presses the ring and bottom together and makes them join. Fig. 257 shows a machine of this kind, made by Wm. Boulton, Ltd., Burslem.

Some crucibles may be made on a kind of jolley, as described in the section on Carboniferous Fireclay Goods.

The relative value of goods moulded by hand or by mechanical pressure is often disputed; the former are more porous and their value depends on the care taken by the workmen, but the latter have the defects previously mentioned as belonging to all pressed goods. In most cases, both processes are equally good, but the cost of installing moulding machines limits their use to large quantities of similar pieces. Hence many potteries still prefer hand-made saggars.

The drying of fireclay goods, when thin or of a small size, does not present any special difficulty; it is done by the same methods as those employed for plain building bricks. Thick and heavy goods which are difficult to handle, and which, unless made in a warm dry climate, can only be completely dried in artificially heated dryers, often cause much trouble.

When moulded by hand, the goods are usually left in the mould for about twenty-four hours, and are then taken out and carried to the drying-shed. This is a room heated either by (1) pipes running under the floor; or (2) by means of a hot-air stove. In the former case, the waste heat from the kilns or from the steam-boiler can be used. The drying must be done very slowly when the pieces are thick; sometimes several weeks are needed. In theory, it is better to have several drying-sheds, so as to graduate the temperature according as the drying advances. From time to time, if the shape will permit, the pieces are turned over so as to render the drying uniform.

In some potteries, the drying is done in the moulding shop, which should be heated, unless favoured with a warm climate.

The burning of fireclay goods is usually done in round down-draught kilns, like those described on page 222 (Fig. 146). The capacity of these kilns varies from 1400 to 5000 cub. ft., the diameter being equal to or slightly greater than the height.

According to the amount of moisture in the ware, and to its size, the slow firing (smoking) may vary from twelve hours to two days. The full firing needs two to three days. The consumption of fuel is extremely variable, owing to the nature of the body, the temperature at which it is burned, and the skill or otherwise of the firemen. In

some works 200 lb. of coal of a good quality to a ton of ware is sufficient; in others, it is necessary to use 550 lb. and even 670 lb. In kilns of the same type, equally well managed, the higher the temperature of burning, the better is the quality of the goods.

For burning bricks and blocks, continuous kilns may also be used. In these, the consumption of fuel is reduced by 176 to 264 lb. per ton of ware, so that it is more economical to use this class of kiln, though if the fuel is burned in contact with the goods some of them will be spoiled. The use of gas in continuous chamber kilns needs slightly more fuel, but the goods are kept free from ash and are generally well burned, so that this type of kiln is certainly the best for burning fireclay bricks and blocks.

For burning retorts, crucibles, etc., in large quantities, continuous chamber kilns may also be used, but as in this kind of kiln the accumulation of heat is less than in kilns with one chamber, and the heat lost by heating the walls is much greater, there is no reason for preferring them except when, as for retorts, the flames ought to be descending, or when the production (of crucibles, for example) requires a very regular rise in the temperature.

Whilst, in a general way, continuous kilns are more economical for burning fireclay goods, it is necessary to state that they are only of commercial value where the output is large. In the fireclay industry, orders are somewhat irregular; it is difficult to manufacture for stock, because of the various shapes and qualities of the goods, so that, commercially speaking, it is sometimes better to use intermittent kilns, as these adapt themselves better to the needs of a variable business.

General Arrangements of the Works for Fireclay Goods.—The manufacture of fireclay goods is sometimes carried on in brickfields or in tile works. Usually the fireclays found in the neighbourhood are used, and the implements employed in making fire-bricks are similar to those employed for the manufacture of ordinary bricks. The goods thus obtained are generally of a medium or inferior quality, and, on account of their relatively low price, are used for many purposes which do not need a better quality.

Some of the larger works for making metal, glass, gas, faience, porcelain, and some chemical works manufacture all the fireclay goods they need. They prepare the grog from their waste and buy the fireclay. In such works, therefore, there is no need to economize in the price of the clay, as they must have fireclay goods of the right quality, and those which experience has shown to be the best for their own special purpose.

There are also special factories for fireclay goods; they are usually placed near the clay-beds. The cost of the fuel, which is an important factor, also exerts a certain influence on the placing of these factories. In some cases it is best to place the works near a centre of consumption and transport the raw materials.

It is usually necessary to keep all fireclay goods sheltered from the rain, in order to prevent the formation of a very disagreeable

green colour, due to vegetation, and to prevent them from becoming soft and friable.

2. *Aluminous Refractory Goods.*

Aluminous refractory goods are used when it is necessary to have neutral goods, only slightly attackable by alkalies, and resistant to high temperatures. The silicious fireclays, which contain at most 30 per cent of alumina in a natural state, or about 33 per cent when burned, cannot be used for the manufacture of truly aluminous goods. The plastic fireclays, with a proportion of 30 per cent to 35 per cent of alumina, produce goods having from 34 to 40 per cent of alumina, and some very pure clays contain, when burned, as much as 43 per cent of alumina.

Under the term " aluminous refractory goods " are included only those which contain more than 40 per cent of alumina, as this amount is just sufficient to combine with all the silica to form a bisilicate, and theoretically only those goods can be properly called aluminous which contain more alumina than pure clay. It is therefore necessary to introduce even into the most plastic clays a supplementary quantity of alumina.

Unfortunately highly aluminous minerals are rare and often costly, and only halloysite or lenzenite and the bauxites can be profitably used. Among the last, the varieties containing the least iron oxide (under 5 per cent) should be chosen. Although these bauxites are hydrated alumina, they are destitute of all plasticity, and cannot be used except as non-plastic materials, that is to say, their proportion when calcined should not be more than 56 per cent. If a fairly pure plastic clay, containing when burned 33 per cent of alumina, 60 per cent of silica, and 70 per cent of fluxes, is mixed with a bauxite containing 79 per cent of alumina, 15 per cent of silica, and 6 per cent of fluxes, a ware could be made having a maximum of 56 per cent of alumina with 38 per cent of silica, that is to say, which corresponds to aluminium monosilicate which is needed to obtain really neutral goods.[1]

Bauxite is found as a rather hard rock and as an earth, and owing to the large proportion of combined water it contains it must be well calcined and reduced to powder before being mixed with the clay. It must not be mistaken for fireclay grog, for the latter, having the same composition as the clay, does not alter the composition of the body. The bauxite, on the contrary, must be very intimately mixed with the clay, so that the mass may be homogeneous. The result is that the goods, thus obtained, are dense, and resist the action of ashes or kiln gases well, but bear rapid changes of temperature badly.

[1] It has recently been found that a material corresponding to $3Al_2O_3 2SiO_2$ (*mullite*) is more stable and preferable to the monosilicate. Mullite contains 71·84 per cent of alumina and 28·16 per cent of silica.

The manufacture of aluminous goods is the same as that of fireclay goods, and is carried on in the same works.

Attempts to bind bauxite powder with different agglutinants, as tar and silicate of soda, have been made; the manufacture of articles from such a mixture is similar to that of silicious fireclay ware (see later).

3. *Carboniferous Fireclay Goods.*

The carboniferous fireproof goods fulfil all the conditions required in fireproof materials: resistance to the highest temperatures, to rapid variations in temperature, and to ashes and other materials with which they may come in contact, but they have the disadvantage of being burned up rather rapidly and of being costly. They are seldom made into bricks or blocks, but are much used for the manufacture of plumbago crucibles, which are employed in several metallurgical operations on account of their reducing qualities.

The carbon used is natural graphite or blacklead, or even the deposit of carbon known as *retort graphite*, which is found in gas retorts.

Graphite or plumbago is a mineral of a metallic, grey colour, crystalline, greasy to the touch, and leaving marks on the fingers. Its density is 2·1. It is found in France, Germany, England (at Borrowdale and Keswick, Cumberland), Austria, and in several parts of Moravia and Styria; in the United States at Sturbridge (Massachusetts), at Ficouderora (New Jersey), at Fishkill (New York), and in some localities in California; important beds are found on the Island of Ceylon, in the Batougal and Ural Mountains, and on the banks of the river Anotte in Siberia. It only occurs in primitive strata along with gneiss, granite, and mica-schists. The proportion of carbon varies from 75 to 97 per cent, the remainder being a silicious or silico-aluminous gangue.

The carbon from gas retorts is generally purer, but the price has risen considerably since its use in large quantities in the electrical industry.

Coke is sometimes used instead of graphite, but is much more porous and less durable.

Carbon, in whatever form it may be employed, is first powdered, and then mixed with the powdered clay. The quantity of carbon used varies from 25 to 50 per cent, according to the purpose for which the crucible is to be used. A part of the clay may be in the form of fine grog. Sometimes magnesia is also added.

The measuring and mixing is first done in a dry state, and the mass is then put into a pug-mill, the proportion of water necessary for moulding being added; the pugged body is left for several days without being used, and is afterwards re-pugged or ground in a wet pan-mill.

The moulding is done mechanically, as it is necessary to compress the material. For this purpose a jolley (Fig. 258) is generally used.

The exterior mould, either of plaster or cast-iron with a movable bottom, is placed on the table of a turning lathe, which is set in motion by means of pulleys or a hand fly-wheel; the required quantity of the body having been put in the bottom of this mould, a plunger is lowered and makes a rough form. Then, by working a lantern wheel, this plunger, which is in two pieces, is forced open, and compresses the body sideways against the outer mould. This compression is made stronger by the upper rim which carries the plunger, and prevents the body from going out at the top. When the plunger is fully open, a final pressure is given by working the hand fly-wheel; after which the plunger is closed and raised and the mould emptied. Sometimes the plunger rotates and not the mould. Large crucibles for melting steel are chiefly hand-moulded.

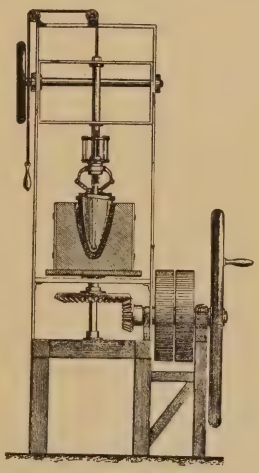


Fig. 258.—Jolley for moulding crucibles.

The crucibles, when made, are dried for some time in the moulding shop, and are afterwards placed in hot-air stoves.

The drying being finished, the crucibles are heated in muffle kilns to a temperature of about 700° C. Round down-draught kilns are sometimes used, the goods being then placed in saggars.

4. *Silicious Refractory Goods.*

Silica is less refractory than alumina, but, as the ores of alumina are nearly always impure, while numerous beds of silica can be found which only contain traces of fluxes, some refractory articles which resist high temperatures are preferably made of silica than of fireclay. These silicious wares are decidedly acid, a property which is desirable in some metallurgical operations, and, as they tend to increase in volume when in use, by making due allowances, very close an non-shifting masonry can be built.

Nearly pure silica is seldom made into any articles other than fire-bricks and blocks; the best known are those from Dinas, where they have been made since 1822, of a sand found in the South of Wales, which contains 97 to 98 per cent of silica. It is mixed with 1 to 2 per cent of lime, made into a paste with water, and the mass is moulded in a press similar to those used for making ordinary bricks of semi-dry body. In some factories a hand press only is used. The moulded bricks should be carefully and well dried artificially, and burned in round down-draught kilns. The "smoking" must be carried out very slowly; then the temperature is

raisep until it reaches 1300° to 1600° C. The cooling should also be very slow ; it is usually done without admitting any air, the heat disappearing simply by radiation from the kiln, as silica bricks are very easily cracked by rapid cooling.

Where there is no natural sand of the quality of that used at Dinas, it is necessary to crush pure silicious rocks to a fine impalpable powder, and to grains of 0·04 to 0·26 in., which are sieved and afterwards mixed with the same material in the form of fine powder in suitable proportions. The best proportions for the mixture seem to be $\frac{1}{3}$ of powder, $\frac{1}{3}$ of grains from 0·03 to 0·12 in., and $\frac{1}{3}$ grains 0·12 to 0·26 in. The processes used for grinding the rocks have already been described ; it is wise to calcine them first, so as to make them more easy to grind. Afterwards $1\frac{1}{2}$ per cent of lime is added to the silica, and the making is continued as described for Dinas bricks.

The lime not only supplies some of the plasticity necessary for moulding (though the very fine silica has a plasticity sufficient for moulding bricks), but it is chiefly used for giving a greater strength to the burned ware, as it forms a silicate of lime which binds the silicious grains together. A much larger proportion of lime would make the ware too fusible. Lime has recently been replaced advantageously by calcium chloride dissolved in water, which decomposes with the heat ; the chlorine is given off, and the lime alone remains, but more finely divided in the mass than when added direct.

Attempts to replace the impalpable powdered part of the silica, which is necessary to obtain a certain plasticity, by adding clay instead, is not desirable, as the refractory properties of the ware would thus be materially diminished (Fig. 254), but such semi-silica bricks have a large sale.

Other binding materials such as silicate of soda, tar, treacle, etc., do not give results to be compared with lime.

When very light bricks are wanted, which have not to resist very high temperatures (as those employed in locomotive or marine boilers), infusorial earths, mixed with a little fireclay (p. 43), may be used with advantage, the manufacture being the same as that of fireclay bricks.

Some silicious bricks are made with the sand which has been used for polishing glass. This sand is moulded in presses, and the ware, when made, is dried and burned at a moderate temperature. The sand particles are cemented together with the rather large proportion of glass which this sand contains. The white bricks thus obtained have a beautiful decorative appearance, imitating stone, but containing too much flux to be considered as a refractory material.

5. *Basic Refractory Goods.*

Basic refractory goods usually owe their properties to the proportion of magnesia or lime which they contain. *Magnesia* is slightly

more fusible than alumina, but it can more easily be obtained nearly pure, i.e. containing only about 2 per cent of lime and 1 to $1\frac{1}{2}$ per cent of silica, oxide of iron and clay. When it is calcined above 400° C. it loses its water of combination. Heated to a lower temperature, it may afterwards absorb moisture from the air, and be changed back into the hydrate.

Calcined magnesia is usually mixed with some magnesia that has simply been dried, and a body is obtained which is sufficiently plastic to be moulded into bricks, and which has even been used for making crucibles or retorts, especially if a little plastic clay is added to it. Very refractory bricks should be made with a press ; they may be dried first in the open air, then in a heated drying-shed ; the burning is the same as for ordinary fireclay goods, but at a higher temperature.

The manufacture of magnesia bricks is relatively recent ; most magnesia bricks are obtained from carbonate of magnesia or giobertite or breunnerite (sometimes called *magnesite*) from Frankenstein (Silesia) and the Isle of Eubœa. The mineral is calcined at a high temperature to decarbonate it ; then a sufficient quantity of water and raw material is added to it, and the resultant paste is moulded in hydraulic presses. The plasticity, which is very slight, may be increased by moistening the mass with a solution of magnesium chloride. After being dried the bricks are burned at a high temperature, but this is often difficult on account of their great shrinkage.

The Silesian magnesite differs from the Grecian in containing a larger proportion of iron oxide. This combines with the magnesia during the first calcination or *dead-burning*, forming a fusible ferrate which acts as an excellent binder and avoids the necessity of adding raw magnesite.

As magnesite does not occur in marketable quantities in England, it is customary to use dolomite or a magnesium limestone, as a mixture of lime and magnesia seems to possess the same refractory qualities that each of these bases has by itself, though any silica and alumina present rapidly increases the fusibility. Bricks made of these materials are fairly cheap as compared with the preceding ones, but are only suitable where it is necessary to use basic materials, but not for very high temperatures. They are manufactured by grinding the raw materials to a paste which is afterwards moulded in a press. The drying is very slow. The burning is difficult, because the shrinkage of the bricks is very great, and is not lessened, as in bricks made of giobertite, by previously calcining the material. Even if the dolomite or magnesium limestone were to be calcined prior to its being made into bricks, the product would usually be inferior to magnesite bricks, as lime is so sensitive to the action of moisture that bricks containing it lack durability. There is, however, scope for some means whereby bricks can be made of dolomite or magnesium limestone, in which this disadvantage can be overcome.

Lime is one of the most refractory materials known, but even

when thoroughly well burned it retains the property of being hydrated in air, so that it is not possible to preserve goods made of lime in an atmosphere that is not absolutely dry. Except to a very limited extent in some electrical kilns, it is not possible to use bricks made of lime except by combining it with alumina and iron oxide. Lime cannot be added to silica, as that forms silicates of lime, which are much more fusible than the silicates of magnesia. The manufacture of bricks of lime is similar to that of dolomite, and involves the same difficulties.

6. *Fireclay Mortar or Cement.*

The material used as mortar in furnaces, kilns, etc., is furnished by the makers of refractory goods; it should have the same composition as the goods. The material is ground to powder and put in sacks. Water only is added to it immediately before use.

As the material ought not to contain any coarse particles, only fine sand or finely powdered grog can be added. Sometimes fireclay alone is used, but it shrinks excessively when heated; it is best to open it with more grog than the body used for the bricks, *i.e.* until it has only as much plasticity as is absolutely necessary for it to be used with a trowel.

For silicious or basic goods, a suitable mortar may be made if a little clay is added to the body to give it sufficient plasticity.

Similar mortar is also used for stopping cracks in masonry or in crucibles and retorts. Many special cements and mortars for furnace work are in use; some consist of a mixture of fireclay and ganister (p. 43) in such proportions that the expansion of the latter neutralizes the shrinkage of the former; others consist of fireclay and grog, or of these materials with a little Portland cement or silicate of soda to make the mortar set prior to lighting the furnace.

A similar material to ganister may be made artificially by using crushed quartzose rocks, to which is added about 10 per cent of clay. This mixture is suitable for high temperatures; or some flux may be added to it, so that the mortar may commence to vitrify at a lower temperature and to make it adhere to the furnace or bricks.

7. *Tests for Refractory Goods.*

It is only within the past fifteen years that refractory goods have been the object of any general method of testing. Having regard to the very different conditions under which they are used, it may well be argued that actual use is the only means of obtaining absolutely conclusive results, but this is not satisfactory to the manufacturers of such goods, who would like to give their patrons numerical results to prove the quality of their wares. Several standard specifications for fire-bricks have been adopted in different countries, the one recognized in England is that issued by the Institution of Gas Engineers,

which deals chiefly with the amount of shrinkage on re-heating for two hours at 1400° C., and on the refractoriness of the bricks.[1]

Exact chemical analysis of the bricks is often an important basis of comparison. It is so complicated, and the quantities to be tested are often so small, that it can only be done by competent chemists. The measurement of refractoriness or temperature at which the goods begin to vitrify or lose their shape, or that at which they fuse, can be made in test kilns such as those described on page 200. The most practicable standard at the present time seems to be Seger cones. The material to be tested should, preferably, be in the form of a Seger cone (Fig. 171) with $\frac{1}{3}$ in. sides and 1 in. high. Alternatively, a piece 2 in. cube may be heated under a pressure of 50 lb. per sq. in. and the change in its height at various temperatures may be noted; this is known as a test of *refractoriness under load*.

For comparing the ability to resist rapid changes in temperature, nothing has been discovered better than heating a test piece to redness and then plunging it into water, or to a blast of cold air of constant dimensions and pressure.

The measurement of the coarseness of the grains, expansion or shrinkage when heated to or maintained at a certain definite temperature, and of the porosity, give interesting comparative results.

The subject of refractory materials is so large and so complex that the present chapter contains only a brief outline of it. For further information the reader should consult the book mentioned in the footnote below.

[1] For further details, see the author's *Refractory Materials: their Manufacture and Uses.*

CHAPTER XII.

FAIENCES.

Classification.—Faience (from Faenza, a town in Italy) is a kind of pottery with a porous body, either white or coloured, but always covered with a glaze; the existence of this glaze distinguishes faience from terra-cotta. Some potters do not admit of this definition, but the author agrees with Deck: "I call 'faience' all ware of an earthy fracture (consequently porous) covered with an enamel."

It may appear strange to term an enamelled brick or tile "faience," but there are stoneware and porcelain bricks and tiles; so it is difficult to see why there should not be faience ones. The meaning of the term "faience" has been considerably widened since the time when it was only used to denote Italian wares of the fifteenth and sixteenth centuries, and it is a singular anachronism to apply it to the ware of the Persians. But it is better, by accepting the clear and precise definition of the celebrated faience manufacturer, Deck, to get away from the confusion that has arisen from Brongniart's classification. The advantage of having a single word to denote all porous wares covered with a glaze is especially felt if the French terminology is compared with that used in England and Germany. There is no common English term to denote all classes of faience: *Majolica*, *delft ware*, *earthenware*, *flint ware*, *ironstone*, *queen's ware*, etc. In Germany, *Steingut* denotes the "fine faience" of Brongniart, but all the other faiences have a series of names: *glazed terra-cotta*, *Majolica*, *Irden-geschirr*, etc., without any general designation being universally adopted.

The term faience having been adopted to designate all porous wares covered with a glaze, it is not necessary to distinguish, as Brongniart does, between "fine faience" and "common faience" the wares from Urbino, from Rouen, and all the silicious faiences, which include some of the most beautiful productions of ceramic decoration. It was certainly not the intention of Brongniart to cast a slur on these latter wares, the adjectives "fine" and "common" being applied by him to the bodies, which are entirely hidden by the glaze, and not to the quality of the ware.

By being satisfied by defining precisely the principal kinds of ware, and with grouping together those which, by the similarity of their properties, are most like one another, it is possible to distinguish six kinds of faience, forming sufficiently well-defined groups,

in which may be classed nearly all wares of this order. The distinctions are based upon the composition of the body, and to a certain extent that of the glaze. The classification adopted in this chapter is the following :—

(1) *Common faience, with a fusible argillaceous body*, in which the fluxes are in a sufficiently large proportion to make the body fusible, without any of them being in an overwhelming proportion. This body is the same as that used for many kinds of terra-cotta. It is formed of one or more clays, natural or washed, with the sole addition of sand, or grog, if necessary. The glaze is plumbiferous, or alkaline boracic.

The principal varieties of this kind of faience are the following :—

Common pottery, architectural faience, encaustic tiles, stoves ; vases, dishes, and decorative objects.

(2) " *Enamelled* " *faience, with a fusible argillaceous calcareous body*, which is formed of a natural marl or of a mixture of clay with marl, or with calcium carbonate ; the glaze is stanniferous or plumbiferous. The term " enamelled " is improper here. Sometimes the word stanniferous is used ; this is still worse, as the tin is only to make the glaze opaque, and its presence in a glaze gives no indication of the composition of the body. The word has only been used in default of another, and not to depart from a terminology which has become customary.

(3) *Silicious faience, with a fusible silicious body*, containing little clay, much silica, and a good proportion of alkaline fluxes or limestone. This very slightly plastic body is made by the addition of non-ferruginous plastic clay and lime or alkalies to silica. The glaze is alkaline plumbiferous.

(4) *Pipeclay faience, with a slightly fusible argillaceous calcareous body*, formed of a mixture of fireclay or kaolin (china clay), and a small proportion of calcium carbonate or marl. The body is decidedly plastic, and needs a higher temperature for burning it than the preceding ones. The glaze was formerly alkaline plumbiferous, but now alkaline earthy bases and boracic acid are often added to it.

(5) *Flint faience, with a fireproof argillaceous silicious body*, formed of a mixture of white fireclay or kaolin (china clay) and a large proportion of silica. The body is somewhat plastic, and must be burned at a high temperature. The glaze is plumbiferous, alkaline, alkaline earthy, or boracic.

(6) *Felspathic faience, with a slightly fusible argillaceous alkaline body*, usually formed of a white or almost white-burning clay (kaolin or ball clay), silica, and an alkaline flux in the form of felspar or pegmatite. The glaze is plumbiferous, alkaline, alkaline earthy, or boracic.

1. *Common Faiences, with a Fusible Argillaceous Body.*

Common plumbiferous ware has been in general use for all domestic purposes since the twelfth century. The body is a simple

clay such as that used for bricks or tiles, or a fusible clay, generally a ferruginous calcareous one, with the addition of sand or grog to make it less sensitive to variations in temperature. The resistance to irregular heating is greater the larger the proportion of non-plastic materials. In this direction, the only limit is the necessity for keeping the body sufficiently plastic for it to be shaped.

The shaping is almost exclusively done by throwing, the handles, spouts, or feet being fastened on afterwards. The goods are easily dried in the workshops. When the drying is finished, the glaze can be put on the unburned ware, or the body may be burned first, the glaze applied and the ware subjected to a second burning.

The glaze, which is thin and transparent, is only used to make the body impermeable. It usually consists of a mixture of a lead compound (such as red lead, litharge, white lead, or galena) and sand, a little clay (5 to 20 per cent) being sometimes added to ensure better adhesion to the ware. When fired, this mixture forms a lead silicate whose fusibility is in proportion to the amount of lead present. The composition of it usually varies between silica 28·8, lead oxide 71·2 per cent, and silica 44·7, lead oxide 55·3 per cent; the first composition having the formula $PbO, 1\frac{1}{2}SiO_2$, and the second the formula $PbO, 3SiO_2$. The use of clay makes a glaze less fusible, so that it may be necessary, if it is present, to modify the relative amounts of silica and lead oxide. In any case, there should be at least one and a half equivalents of silica to one equivalent of base, to ensure all the lead oxide being combined. If the proportion of silica is above three equivalents of the base, the glaze usually becomes too infusible to be used on this kind of ware.

The glaze is colourless, but is often slightly coloured by the oxide of iron contained in the clay, and then the ware is a brighter colour than the body. Sometimes 5 to 12 per cent of manganese oxide is added to produce a brown colour, or 2 to 3 per cent of copper oxide (scales of red copper) to give it a green colour, the shade of which is modified by the colour of the body beneath.

The inside of vases is sometimes covered with a white opaque glaze, usually obtained by adding 10 to 15 per cent of tin oxide to the preceding glaze, and at the same time reducing the proportion of silica so as not to alter the fusibility. Any clay present ought, in this case, to be a white burning one.

The glaze is generally applied by pouring, sometimes by dipping, and seldom by dusting.

This ware is often burned in up-draught or in horizontal kilns with one fireplace, but it would be more advantageous to use round down-draught kilns. For large quantities, which are rare, it would be better to use continuous chamber kilns or even a tunnel kiln.

Common ware is manufactured in small local potteries near the clay pits. The quality of the ware depends almost entirely on that of the clay that is used. The ware is cheap and, however rough it may be, it is useless to improve it greatly, because that would only make the ware more expensive without the quality being comparable to that of other wares.

Among the common plumbiferous wares may also be classed some pipes used for conveying liquids, the inside of the permeable body being covered with a thin, transparent plumbiferous glaze. These pipes, made by throwing or expression, were formerly very much used, but are now almost entirely replaced by salt-glazed stoneware pipes.

The employment of a plumbiferous glaze presents certain dangers in pots intended for cooking food. When the firing temperature is not high enough to combine all the lead oxide with silica, or when the glaze does not contain enough silica (many compositions given in works on pottery are of this kind), any uncombined lead oxide may be dissolved by the acids in the food and cause poisoning.

The following method of testing will show whether any ware is harmless: Boil some vinegar gently for about half an hour in the pots to be tested, filling up the liquid with water as it evaporates, and making the volume in proportion to the capacity of the pot (the volume of vinegar should be at least one-tenth of that of the pot). When the liquid has been sufficiently heated it is allowed to cool, is filtered, and some sulphuretted hydrogen dissolved in water is added to part of the clear solution, or a current of this gas is passed through it. The presence of lead will be detected by a black precipitate or else by a brown colour. In another part of the solution some potassium iodide solution would produce a yellow precipitate of lead iodide if sufficient lead were dissolved out of the ware. Various other methods of carrying out this test have been proposed, and the maximum amount of lead which may safely be dissolved from 1 sq. in. of pottery surface has been suggested. In most ware, the first treatment with acid dissolves out far more than any subsequent treatment so that most plumbiferous ware may be rendered safe by heating it once with vinegar.

Common Non-plumbiferous Ware.—Cases of lead poisoning have been serious enough to cause numerous researches for the purpose of replacing plumbiferous glazes by other compounds that do not contain lead. The problem is very difficult, as the glaze must not be made too fusible and the price must not be increased out of proportion to the low value of the ware. Thus, the lead oxide may be partly replaced by alkali, usually introduced in the form of silicate of soda or soluble glass, but soda or potash can be used direct so as to obtain a double silicate of lead and alkali. The chemical composition of these glazes may be represented by the formula

$$1\left\{\begin{matrix}\mathrm{PbO}\\ \mathrm{K_2O\ or\ Na_2O}\end{matrix}\right\}1\text{-}1\tfrac{1}{2}\mathrm{SiO_2}.$$

If it is advisable to omit the lead entirely, lime must be introduced into the glaze, so as to obtain an insoluble glaze, and part of the silica must be replaced by boracic acid, to increase the fusibility. According to Seger, it is also necessary for the glaze to contain a certain proportion of alumina (clay) to make it sufficiently

transparent, the composition of the glaze being between the limits of the two following formulæ :—

$$\left\{\begin{matrix}0{\cdot}6K_2O \text{ or } Na_2O\\0{\cdot}4CaO\end{matrix}\right\}0{\cdot}5Al_2O_3,\ 4SiO_2,\ 0{\cdot}5B_2O_3$$

and

$$\left\{\begin{matrix}0{\cdot}2K_2O \text{ or } Na_2O\\0{\cdot}8CaO\end{matrix}\right\}0{\cdot}6Al_2O_3,\ 5SiO_2,\ 1B_2O_3,$$

which correspond approximately to the following proportions :—

Silica	60·5	58·6 per cent.
Boracic acid	11·5	18·0 „
Alumina	13·0	12·0 „
Lime	5·6	9·0 „
Alkalies	9·4	2·4 „

The relative amount of lime and alkalies depends on the composition of the body ; alkaline glazes having to be applied to silicious bodies and calcareous glazes to aluminous bodies.

A white glaze may be obtained by adding 10 to 12 per cent of tin oxide to the glaze if the body is slightly coloured, or 12 to 15 per cent for ferruginous bodies. If this addition reduces the fusibility, the proportion of boracic acid may be correspondingly increased.

Some glaze merchants sell leadless glazes, the composition of which they keep more or less secret, but these substances cannot be adapted indiscriminately to any body, as can the plumbiferous glazes, by the simple addition of silica or clay.

The addition of heavy spar or witherite to these glazes has also been suggested, but these substances present difficulties which are not easy to overcome in works making common ware.

Architectural faiences such as bricks, tiles, paving tiles, and architectural terra-cotta, mentioned in Chapter X, may be covered with glaze, this use of glaze dating back to the remotest antiquity.

At the present time, the body used for architectural faience is usually a red-burning fusible clay, but within the last twenty years fireclay has been chiefly used for glazed architectural terra-cotta, as this can be glazed with a highly felspathic, leadless glaze, which must be burned at about 1300° C., and is much more resistant to exposure than most plumbiferous glazes. Such glazes are the same as those used for sanitary ware made of fireclay. All terra-cotta bodies cannot receive glazes, as, independently of the agreement necessary between the glaze and the body, it is essential that the latter should have a fairly smooth surface and not be too porous. These defects may be partially corrected by smoothing the body after it has been moulded, or by covering it with a thin slip.

The composition of the glazes and their application depend on the composition of the body, on its colour and on that of the glaze. If the body is inclined to orange or red, a transparent plumbiferous glaze gives it an intense red colour. By adding to this glaze 5 to 8 per cent of manganese oxide, darker or lighter brown colours

are obtained. A mixture of iron and manganese oxides with a touch of cobalt makes black. All other colours can only be obtained on a red-burning body by means of intermediate slips or opaque glazes.

With yellowish bodies, the series of transparent colours available is much richer. Lead silicate alone gives yellow. Lead silicate and iron oxide or manganese produces the preceding various red and brown colours. Green can easily be obtained by means of copper oxide and blue with cobalt oxide. Only light colours and white need to be opaque or applied on an intermediate body or engobe.

It is only exceptionally that an article made of white body has to be slipped, as with a colourless glaze, white ware can be produced. A light yellowish tint, however, may be hidden by a glaze containing a little cobalt.

The coloration of architectural faience resolves itself into the employment of :—

(1) A transparent glaze on a body covered by coloured slip.

(2) Transparent coloured glazes.

(3) An opaque white glaze, which may be slightly coloured for light tones.

There are many conditions of manufacture, colour, and shape of the wares, which limit the use of slips or coloured glazes ; it is impossible to give any general rule for them.

Colourless, transparent glazes on red-burning ware are nearly always plumbiferous ; their composition is usually one equivalent of lead oxide to 2, 2·5, or 3 of silica, that is to say, it usually varies from 60 to 55 per cent of lead oxide for 40 or 45 per cent of silica. The most silicious bodies are used with the most plumbiferous glazes.

Coloured glazes are generally formed from the preceding plumbiferous glaze, with the addition of colouring oxides in the proportion of $\frac{1}{2}$ to 5 per cent, according to the shade required, the amount of silica being slightly varied, so as to control the fusibility. If, in spite of this correction, the glaze is still too fusible, the proportion of alkali may be lowered, or a little lime or oxide of zinc added in place of the lead, as these are more refractory.

To obtain certain colours it is necessary to introduce alkalies into the glaze, part of the lead oxide being replaced by alkali. The proportion must, in no case, be above one equivalent of lead for one of alkali : the chemical composition in that extreme case being

$$\left.\begin{matrix} 0{\cdot}5Pb_2O \\ 0{\cdot}5K_2O \text{ or } Na_2O \end{matrix}\right\} 3SiO_2.$$

The amount of silica should not fall below $2\frac{1}{2}$ equivalents.

Boracic glazes are seldom employed for architectural faience, because the degree of fusibility required can always be more economically obtained with lead oxide.

Opaque white glazes are more difficult to produce, as the opacifying material lessens the fusibility of the glaze. If the body contains

a large proportion of lime, the white enamel for enamelled faience, mentioned later, may be used. If such is not the case and the body is slightly coloured, an enamel composed of 60 per cent of lead oxide and 40 per cent of silica, with 10 to 12 per cent of tin oxide, may be used, though for highly coloured bodies this enamel is not opaque enough, and it is often too refractory. Boracic acid must then be employed as a flux, replacing some of the silica. Such enamels may be roughly represented by the formula—

$$\left.\begin{matrix}0{\cdot}7PbO\\0{\cdot}3CaO\end{matrix}\right\}1{\cdot}5SiO_2,\ 0{\cdot}5B_2O_3 + 10 \text{ to } 12 \text{ per cent } SnO_2,$$

though all the proportions may vary, according to the nature of the body and the degree of fusibility to be obtained. Further, the whole or part of the lead oxide may be replaced by alkali, but the amount of silica must be increased, and the product then resembles the glazes used for the common non-plumbiferous wares just mentioned.

The glazing is done by different methods : (*a*) By dipping, for bricks, which are always glazed on one or two faces only ; (*b*) by spraying, which is used for large blocks and for tiles and paving tiles. Other kinds of architectural faience are glazed by one of these methods, unless the glaze can be put on with a brush, which is compulsory when the pieces are many-coloured. When the goods are round, this application with a brush may be more easily made by turning them on a wheel, the brush being moved only when a whole turn has been accomplished.

The glaze is generally applied to the unburned dry body ; for some more delicate objects it is preferable, however, to apply the glaze to the burned body.

The burning may be in the continuous kilns used in tile works or brickfields, especially if the glazed or enamel goods are carefully protected, but it is generally preferable to burn architectural faience in a muffle or in saggars in round intermittent kilns. The atmosphere of the kilns must always be oxidizing, and the full firing should be short enough to prevent too great a volatilization of the lead oxide or of the boracic acid.

All the methods mentioned in Chapter IX, and especially gilding, may be used for decorating architectural faience. Successful attempts have been made to lessen the gloss of the glaze by diminishing its fusibility, especially by adding to it a larger proportion of silica. Vitrification is then not complete, and the surface remains dull or *matte*, without having the completely dull look of the ware slipped with body.

The resistance of architectural faience to the weather, and especially to frost, is important, and it is evident that the body itself must fulfil the conditions of resistance mentioned in connexion with terra-cotta, and that under-burned bodies must not be covered with a glaze, as has sometimes been done.

If a highly resisting body is used, it is easy to see that the glaze

diminishes rather than increases the resistance. If the body when saturated with water is subjected to frost, the ice formed in the pores exercises, on the whole interior surface of the glaze, a pressure which tends to detach it, or at least to make it crack. To remedy this defect it is necessary to obtain a close union between the body and the glaze, the latter penetrating sufficiently deeply into the pores of the body, and not simply forming a layer on the surface. This object is attained by giving the glaze a composition which allows it to harmonize with the body, and even to act upon it chemically. Thus, a strongly alkaline glaze would adhere better to a silicious body than to an aluminous one, in consequence of the combination of the alkalies of the glaze with the silica of the body. The opposite effect is more difficult because the excess of silica in the glaze, which would be sufficient to act upon a basic body, would make this glaze difficult to vitrify. It is also necessary that the vitrification should be complete and sufficiently prolonged to allow the glaze to penetrate well into the body, and to give time for the requisite chemical actions to take place.

Faience manufactured under these conditions would resist all weathers, as has been proved by numerous examples of faience in the Middle Ages, employed outside buildings, which have remained intact up to the present day. Nevertheless, it is prudent to place the faience in such a way that the surfaces which are not enamelled should not be too much exposed. This condition is nearly always easy in walls ; roofs should have an ample slope.

Encaustic tiles deserve a special place among architectural faiences, because of the great development which took place in their manufacture in the Middle Ages. These tiles are usually square, of small size, and from $\frac{3}{4}$ to $1\frac{1}{4}$ in. thick ; their manufacture includes the following operations :—

(1) Moulding the tiles by hand from a clayey body.

(2) Stamping a design on them in hollows by means of a block, when the tiles are partially dried.

(3) Filling the hollows thus obtained with a liquid body of a different colour from that of the tile, and scraping off the surplus material by means of a metallic straight-edge.

(4) Beating the stiffened tiles to harden their surface.

(5) Glazing the upper surface of the dry tile by spraying it with a plumbiferous glaze.

(6) Burning them in muffles or saggars.

This method of making the tiles may be simplified by moulding them in a press, using a metallic mould in the bottom of which is placed a little piece of metal with a projection equal to that of the hollow required. A rough cake of fine body is put into the mould, then a thicker slab of coarser body is put over it, after which a stroke is given with the press to mould and weld the whole together. The employment of two different bodies is to economize the more costly fine body. The rest of the manufacture takes place as described.

The tiles are generally yellow, orange, red, brown, or black.

The slips may be coloured green or blue by copper, chrome, and cobalt oxides. As they are put on with a more liquid body than that of the tile, they would shrink more and become detached if the precaution were not taken of putting more non-plastic material into them. The glaze is a lead silicate, and does not differ from those already described for the preceding wares.

Vases, dishes, and decorative objects were decorated with plumbiferous glazes by the Egyptians, as is proved by the pottery found in burial places, but it was not until the twelfth century that glazed pottery was regularly manufactured in Italy, whence it spread in the thirteenth century to France and Germany, and later to England.

The body was always coloured, consequently the colours introduced into the transparent glaze could only give yellow (this only on light bodies), red, brown, and green.

Slips were known to the Greeks and Romans, but they appear to have fallen into oblivion, to be used afresh in Italy in the fifteenth century, whence they spread over the whole of Europe. Since the sixteenth century slip-decoration has only been used for common ware.

Some potters have classed the ware made by Bernard Palissy among enamelled faience, but its composition, as determined by Brongniart, puts it among the argillaceous non-calcareous bodies :—

Silica	67·50 per cent.
Alumina	28·51 „
Iron oxide	2·05 „
Lime	1·25 „

The glaze is distinctly plumbiferous ; any tin present being, according to Deck, accidental, and not to make the glaze opaque ; and whenever Palissy's faiences have been imitated, argillaceous calcareous bodies have been used in preference to stanniferous glazes. The moulding of ornaments, leaves, feathers, animals, fishes, etc., must be done separately, the pieces being afterwards stuck on to the vases or dishes.

The colours of the glaze are yellow and yellow-brown—doubtless obtained with ochres—an indigo blue from cobalt, a greyish-blue, an emerald green from copper, a yellow-green from copper and ochre, a violet from manganese, and a violet-brown from manganese and ochre.

The artistic decoration of glazed faiences has been much developed in recent years, and several important potteries have made a speciality of them.

2. *Enamelled Faience, with a Fusible Argillaceous Calcareous Body.*

Enamelled faience was used for table-ware and for decorative pieces from the sixteenth to the eighteenth century, but is now only used for imitation Moorish, Italian, or French faience, and for the tiled stoves used for heating apartments on the Continent.

According to Brongniart, the composition of some of these faiences is that shown in the following table :—

	Silica.	Alumina.	Iron Oxide.	Lime.	Magnesia.	Undetermined.
Persian faience (fourteenth to sixteenth century) . .	48·54	12·05	3·14	19·25	0·30	16·72
Hispano-moresque faience .	46·04	18·45	3·64	17·64	0·87	13·96
Hispano-moresque faience from Manises	54·71	18·80	2·20	19·69	tr.	4·60
Luca della Robia faience .	49·65	15·50	3·70	22·40	0·17	8·58
Nevers faience . . .	56·49	19·22	2·12	14·96	0·71	6·50
Rouen faience . . .	47·96	15·02	4·07	20·24	0·44	12·27
Delft faience	49·07	16·19	2·82	18·01	0·82	13·09

The last column includes the alkalies and any carbon dioxide present as calcium carbonate, owing to the latter not being decomposed as the temperature for burning the ware is insufficient.

In these bodies, the proportion of lime varies from 14 to 22 per cent, but with the higher temperatures now used for burning such bodies it is better to keep the proportion of lime between 16 and 17 per cent ; below 16 per cent the stanniferous enamel tends to shell, and above 17 per cent the body behaves badly when burned, and unduly absorbs the plumbiferous glaze used to decorate it.

Deck has recommended for the imitation of Palissy ware a body having when burned the composition shown below, but Bourry thinks it better to lessen the proportion of lime and to keep to the bodies of which the composition would vary between the limits shown in the column below his name :—

	Deck.	Bourry.
Silica	65 to 66	60 to 65 per cent.
Alumina	14 to 15	13 to 20 „
Iron oxide	—	2 to 4 „
Lime	19 to 20	13 to 16 „
Alkalies	—	2 to 4 „

All the bodies of ancient enamelled faience and most of the newer ones are entirely covered with an opaque white glaze, which forms the background of any decoration, and has the following composition :—

Sand or flint		45 per cent.
Calcine composed of	Oxide of lead . . .	36 „
	Oxide of tin . . .	10 „
Sea salt		9 „

It is wise to frit the sea salt and the sand first, then to add the calcine and to remelt the mixture. If the whole is fritted together,

the salt may not be completely decomposed, and some of it may escape by decrepitation.

The white enamel may be coloured by the addition of 3 to 10 per cent of one or more metallic oxides. Thus, yellow is obtained by 9 per cent of lead antimoniate, blue with 5 per cent of cobalt oxide, green with 5 per cent of copper oxide, violet with 4 per cent of manganese oxide, and so on.

The body is first burned at a temperature sufficiently high to decompose the carbonates (1000° to 1200° C.), and after it has become cold the enamel is applied either by dipping or pouring; it is then left to dry. The ware may then be decorated either by putting the colours on the unburned enamel and following this by a second burning, or the enamel is burned first and afterwards decorated, the colours being fixed by a third firing.

The first method—called *painting for hard firing on raw enamel*—was the only one used for the Italian, French, and Dutch faiences from the fifteenth to the eighteenth century. As pointed out on page 270, this method presents great difficulties, on account of the friability of the raw enamel, but it gives deep tones which become partly embodied in the glaze. The vitrifiable colours used are generally plumbiferous, but are sometimes alkali-plumbiferous. In Italy and Holland, the raw enamel was formerly sprayed or sprinkled with a second alkaline plumbiferous glaze, which allowed the employment of alkaline vitrifiable colours and gave a greater gloss to the ware.

Painting on burned enamel was employed at the beginning of the eighteenth century by Hannong and the potters of the Strassburg school, the decoration being easily effected with vitrifiable colours. Transparent coloured glazes may also be used by surrounding the different enamels with a black outline, as in cloissonné enamel (p. 270).

The object of the white stanniferous enamel is to hide the colour and defects of the body, hence the name "stanniferous faience" for this class of ware, but as it is now easy to obtain almost white argillaceous calcareous bodies, these can be covered with transparent glazes of varied colours as noted in Palissy's faience. The calcareous composition of the body allows the use of transparent and opaque enamels for light tones, and especially for white, which is so difficult to obtain with wholly argillaceous bodies.

Stove-tiles, panels, and, in a general way, any faience which has to bear irregular heating, must be made of a body similar to refractory terra-cotta; they may be made of fireclay, but are more frequently made of a less refractory clay which has been "opened" by the addition of quartzose sand or grog; unfortunately, the highly porous mass, thus obtained, cannot be satisfactorily covered with glaze until its surface has been covered with a slip. The latter may then be covered with a plumbiferous glaze, but not with an opaque enamel, as this latter can only be fixed to a calcareous body. As, on the one hand, in order to resist heating, an argillaceous,

porous, coarse body is needed and, on the other hand, a compact calcareous fine body is required for the glaze, it is difficult to exactly balance these contradictory conditions. If the tiles are made of a coarse refractory body and covered with a slip of fine calcareous body, the difficulty is simply shifted, as unless there is a good agreement between the two bodies, the slip would shell off. To avoid this difficulty, it is now usual to open a moderately calcareous body by means of sand and grog, and to cover it with a slip made of the same body, only consisting of finer particles, or to use a body of medium composition and texture.

As the physical texture plays so important a part in the composition, it is impossible to give a definite composition for the body, but the following general rules are useful :—

(*a*) The amount of calcium carbonate may vary from 10 to 14 per cent ; below this limit the enamel shells off, above it, the body spilts. The higher proportion is suitable for a body containing very little iron oxide (say 1 to 2 per cent), while the lower proportion is applicable to bodies containing from 5 to 6 per cent of iron oxide.

(*b*) The proportion of alumina should be reduced as much as possible, so that the body has only just enough plasticity for moulding ; the best proportion of alumina is usually about 12 to 14 per cent.

According to Barral, the ancient body used by Pichenot was composed of—

Silica	56·3 to 55·4 per cent.
Alumina	29·2 „ 26·6 „
Iron oxide	0·9 „ 1·3 „
Lime	14·7 „ 13·2 „

and was formed by mixing

Plastic clay	24 parts.
Marl	26 „
Sand	12 „
Fireclay grog	38 „
	100

The grog should contain about half the alumina present in the body.

In Germany, Velten clay is much used for the manufacture of stove-tiles which, according to Seger, contain 45 per cent silica, 11 per cent alumina, 5 per cent iron oxide, 15 per cent lime, and 4 per cent alkalies. The Velten clay, when washed in a Schoene's apparatus (p. 51), is found to contain 73 per cent grains of less than 0·0004 in., 12 per cent grains between 0·0004 and 0·0015 in., 14 per cent grains between 0·0015 and 0·0078 in. in diameter.

The clay is first sorted and prepared as described for refractory argillaceous bodies ; it is then moulded by hand, generally in a plaster mould such as that shown in Fig. 259. A slab (A) is made

as just described ; then a column of body (B) obtained by expression (p. 322) is put on it, and given a rectangular form with rounded corners by joining it to the slab. A round roll (C) is next added to the outside, and flattened in the hand so as to make a *curve* which strengthens the previous weld. Angle tiles for corners are made in the same manner, but the plaster mould must be in two pieces (Fig. 260).

These operations may be simplified by using a machine such as that made by Schlickeysen (Fig. 261), in which a flat cake or bat of body is put in the mould ; a plunger, with the same shape as the hollow interior of the tile, is lowered, and then, by means of two lateral screws, pressure is exerted so as to form the tile. Attempts to mould the tiles in a press without first making a rough form will be abortive.

The drying must be very slow, as the unsymmetrical shape of

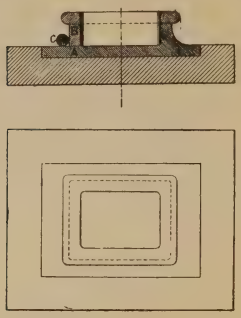


Fig. 259.—Stove-tile mould.

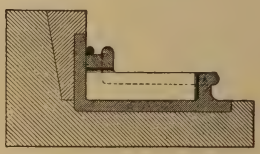


Fig. 260.—Stove-tile mould.

the tile always creates a tendency to bulge, and the dry body must be straightened by striking it on a marble slab or by levelling it on a flat stone.

The tiles are placed open in the kiln, two being set against each other, the "faces" being in contact. The burning presents no special difficulties but it is necessary to straighten any burned pieces which are warped by rubbing them on a large horizontal table, usually of cast iron, covered with polishing sand and water.

The glaze is applied by pouring or by dipping, and is burned in muffle kilns, or, better still, in saggars. Its composition is usually that previously mentioned, though in Germany enamels having a larger amount of alkali are now largely used ; they are composed of limestone (? marble), sea salt, and either a felspathic sand or a mixture of pure sand and felspar, and correspond to

$$\left.\begin{matrix} 0{\cdot}53PbO \\ 0{\cdot}06CaO \\ 0{\cdot}10K_2O \\ 0{\cdot}31Na_2O \end{matrix}\right\} 0{\cdot}21Al_2O_3,\ 3{\cdot}43SiO_2 + 0{\cdot}79SnO_2$$

or

$$\left.\begin{matrix}0{\cdot}56PbO\\0{\cdot}10CaO\\0{\cdot}03K_2O\\0{\cdot}31Na_2O\end{matrix}\right\}0{\cdot}16Al_2O_3,\ 3{\cdot}00SiO_2 + 0{\cdot}46SnO_2$$

Any ornamentation in relief on the surface of the tiles is made by forming corresponding hollows in the plaster mould.

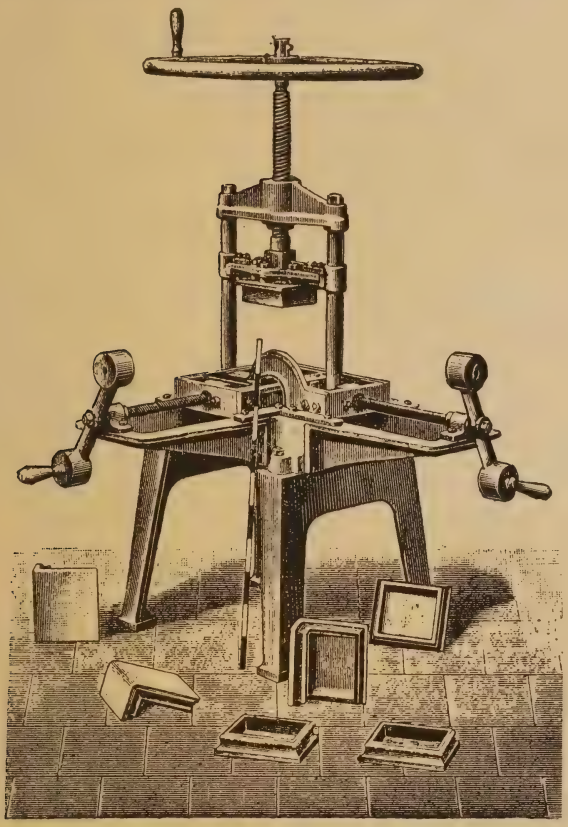


Fig. 261.—Press for stove-tiles.

Stove-tiles are usually decorated with transparent glazes ; the different colours being separated either by a black outline or by engraving deep lines in the mould, which reproduce the design in such a manner as to prevent the enamels from mixing together.

3. *Silicious Faience with a Fusible Silicious Body.*

The earliest kinds of faience manufactured by the ancient Egyptians, and later by the Persians, had an extremely silicious

body composed of sand, alumina, and fluxes (alkalies and lime). The glazes were alkali-plumbiferous silicates, with brilliant colours. Two frescoes which adorned the palace of the kings of Persia at Susa, but now in the Louvre, are among the most beautiful examples of this ancient Persian art. The nature of the raw materials used is still unknown. The slight plasticity of this body must have made the moulding very difficult, unless organic materials were added to the body to give it a certain pseudo-plasticity, and then disappeared when the bodies were burned. The body in an unburned state appears to have been covered with a first glaze, or rather a lustre, composed chiefly of sodium silicate and doubtless intended to fill up the pores of the body, which was then burned at a rather high temperature, probably 1200° C., when, by the action of the fluxes, it would attain a certain hardness. The second glaze, according to Lindhorst, corresponds to the formula—

$$\left.\begin{matrix} 0{\cdot}32PbO \\ 0{\cdot}68Na_2O \end{matrix}\right\} 2{\cdot}82 \text{ or } 3{\cdot}48SiO_2.$$

In 1861, Deck attempted to reproduce these Persian faiences, using quite a different body, but one equally silicious and relatively fusible, namely :—

White earth	24 per cent.
Meudon white	24 „
Flint	48 „
Frit	4 „

The frit was composed of—

Fontainebleau sand	85 per cent.
Potash	7 „
Soda	3 „
Chalk	5 „

Twelve per cent of flint may be substituted for the Meudon white and an additional 10 per cent of frit may be added in making stove tiles.

The biscuit body was covered with a slip composed of—

Frit	63 per cent.
White stanniferous enamel	32 „
White earth	5 „

The exact chemical composition of these mixtures is not known. Deck adds that " it is not absolutely necessary to add frit to the earth to prevent it cracking, as the silica and lime may be sufficient to hinder it, but the frit adds to the intensity of the colours, and the whole article has a more powerful character."

The glaze used by Deck was an alkali-plumbiferous silicate composed of :—

Sand	48 to 50 per cent.
Red lead	30 „
Potash	12 „
Soda	8 to 10 „

The mixture is melted, then powdered, and afterwards applied to the ware; the temperature for burning it is 1000° to 1200° C. The following are the compositions of some of the colours used by Deck :—

Flux.

Silica	70
Red lead	5
Potash	15
Soda	10

Dark Blue.

Flux	50
Red lead	20
Cobalt oxide	30

Light Yellow.

Calcine	62
Red lead	21
Antimony	14
Ammonia	3

Rose.

Silica	14
Chalk	24
Stannic acid	55
Borax	3
Potash bichromate	3
Alumina	1

Red-Brown.

Red lead	20
Calcined Armenian bole	80

Black.

Silica	14
Alumina	3
Red lead	20
Antimony oxide	10
Iron oxide	16
Iron chromate	9
Manganese oxide	18
Cobalt oxide	3
Copper oxide	7

Turquoise Blue.

Flux	47
Red lead	6
Copper oxide	47

Green.

Silica	30
Alumina	5
Flux	5
Red lead	40
Antimony oxide	20
Copper oxide	50
Iron oxide	10
Iron chromate	30

Dark Yellow.

Silica	5
Alumina	2
Calcine	18
Red lead	17
Litharge	15
Antimony oxide	24
Iron oxide	14
Zinc oxide	5

Red.

Red lead	20
Thivier's stoneware	80

Dark Brown.

Zinc oxide	25
Iron sulphate	20
Iron chromate	40
Magnesia oxide	15

White.

Flux	34
Stanniferous white enamel	66

White.

Nevers' sand	34
Chalk	16
Powdered porcelain body	50

These mixtures are diluted with silicate of potash of specific gravity 1·297. The colours, having been mixed on the slab or with a palette knife with a little gum-arabic, are put on with a brush.

The decoration is effected by making cells with a black outline, $\frac{1}{16}$ or $\frac{1}{32}$ in. thick, by means of a mixture of a body, flux, and black colour. The transparent enamels applied so as to fill these cells are :—

Flux.

Silica	50
Red lead	36
Potash or soda	14

Blue.

Flux	83
Silica	14
Cobalt oxide	3

Yellow-Brown.

Flux	44
Silica	20
Red lead	25
Iron oxide	8
Magnesia	3

Deep Violet.

Flux	92·4
Magnesia	7·0
Cobalt oxide	0·6

Turquoise Blue.

Flux	80
Copper oxide	20

Green.

Silica	31
Borax	5
Red lead	55
Potash	5
Copper oxide	4

Grenat.

Flux	82
Soda	5
Nitrate of soda	5
Antimony oxide	2
Magnesia	6

Ivory Black.

Flux	52
Silica	20
Red lead	25
Iron oxide	3

Prior to use, all these enamels are melted, poured into water, and then powdered.

The relatively tender body of these silicious faiences is not resistant enough to be used for domestic purposes, but is very suitable for artistic wares, the moulding of which does not need a highly plastic body, whilst the charm of the decoration consists chiefly in the incomparable brightness of the colours.

4. *Pipeclay Faience with a Slightly Fusible Argillaceous Calcareous Body.*

The so-called pipeclay faiences have an almost white, hard body composed of fireclay, flint, and chalk ; a part of the chalk is sometimes replaced by an alkaline flux. The body, when slightly burned, resembles that used for making clay tobacco-pipes, hence its name, but it has a larger proportion of silica, and is burned at a higher temperature (1200° C.).

The fireclay serves as a base for the composition of the body, and the proportion of silica (sand or flint) added to it depends on the degree of plasticity required. Sometimes a small part of the sand is replaced by grog made of the burned body. If the lime is added in the form of marl, the relative plasticity of which is added to that of the clay, so that more "opening" material is required, in the form of chalk, flint, or grog than if the lime is added in the form of chalk, the latter reduces the plasticity of the body, though in a less degree than silica. When an alkaline flux is added, it is usually introduced as felspar, which, during the shaping and drying of the ware, is as effective an "opening" material as flint. The following are typical bodies of this class :—

Fireclay	40	40	40	25	60
Flint	40	35	35	42	20
Grog	—	5	5	5	—
Chalk	20	20	16	—	16
Felspar	—	—	4	—	4
Plastic marl	—	—	—	28	—

Sometimes china clay is added to the body to whiten the mass.

The glazes formerly used were very tender alkali-plumbiferous silicates of the following composition (Bastenaire) :—

Sand	36
Red lead	45
Carbonate of soda in solution, 2·25 (sp. gr.)	17
Nitre	2

corresponding to the formula—

$$\left.\begin{matrix} 0{\cdot}57PbO \\ 0{\cdot}03K_2O \\ 0{\cdot}40Na_2O \end{matrix}\right\} 1{\cdot}75SiO_2.$$

For many years, alkali-plumbiferous boracic glazes have been preferred.

The following five glazes have been recommended by Prossel :—

Frit.						*Glaze.*					
Felspar	41	35	16	30	24	Frit	90	82	58	65	65
Sand	13	18	39	22	30	White lead	9	8	26	24	13
Red lead	28	16	—	—	—	Sand	—	—	—	—	11
Borax	16	22	29	30	35	Felspar	—	10	16	11	11
Kaolin	3	3	10	3	6						
Potash	1	—	—	4	3						
Chalk	6	6	15	11	12						

To hide the slightly yellowish tinge of the body, one-half to one-thousandth part of cobalt oxide is added to the glaze.

Pipeclay faience is made chiefly in the north-east of France and the west of Germany. Its composition and glaze have gradually changed, and at present are very similar to the felspathic faiences, which are now more generally used, though for cheap ware pipeclay faience is still of service. The methods of manufacture are the same as those employed for felspathic faience (see Section 6, later).

5. *Flint Faience, with a Refractory Argillaceous Silicious Body.*

The body for this kind of faience (*Flint ware*) is almost white, hard, and refractory ; it is made by the addition of flint to a white burning fireclay or kaolin. The flint is burned and ground before use ; the proportion added depends on the plasticity of the clay and varies from 10 to 30 per cent. In order to give added whiteness to the body, part of the clay and flint may be replaced by a silicious china clay (kaolin).

The glaze is plumbiferous, alkaline, or alkaline-earthy and boracic ; its composition is similar to that for pipeclay faience (see section 4). Harder glazes, like those employed for felspathic faience, may also be used.

The body should be burned at a very high temperature, because of the absence of flux, but it never acquires the hardness and gloss of the felspathic faiences, nor even of the pipeclay ones. Flint ware was very much in fashion at the end of the eighteenth century, but is very little used at the present time.

6. *Felspathic Faience*[1] *with a Slightly Fusible Argillaceous Alkaline Body.*

Felspathic faience has a white, slightly yellowish, hard body which, in some varieties, becomes very slightly translucent, thus approaching porcelain. It is made by mixing plastic fireclay or ball clay, china clay, flint, and felspar, or pegmatite. The plastic clay naturally serves as a basis ; to it is added the china clay to whiten the body, as even the purest plastic clays have a yellowish tinge when fired. The flint helps to open the body and to give it whiteness and hardness, and the felspar or pegmatite serves both as a non-plastic material and as a flux. The proportions in which these four substances are mixed are variable ; they depend not only on the composition of the raw materials, but on the quality of the body desired, and on economical considerations.

The English method of manufacturing felspathic faience may serve as a type of all other methods, though the English product is usually superior. The raw materials are : blue ball clay from Wareham and Corfe Castle, Dorsetshire ; china clay from Cornwall ; flint from the pebbles of the Somme, and pegmatite (Cornish stone) from Cornwall. The following are some of the best-known examples of the composition of bodies obtained with these materials :—

Blue ball clay	47	43	31	24	21	18
China clay	24	24	36	27	28	43
Flint	22	23	21	36	38	24
Pegmatite	7	10	12	13	13	15

[1] In England, this ware is known as *Fine Earthenware*, or more commonly as *Earthenware*.

The quality of the body may be varied by altering the proportion of the four constituents or by altering the temperature at which it is burned, as a more intense heat allows of less flux being used.

The glazes are of a similar composition to those used for pipeclay faience (Section 4), but they are usually rather harder and contain more silica and alumina. This hardness may be compensated by a larger proportion of boracic acid. The following, according to Prossel, are the compositions of several of these glazes :—

Frit.

Cornish stone	—	—	31	25	—	41
Sand . .	35	28	17	10	26	24
Borax . .	35	—	30	—	—	32
Boracic acid	—	17	—	18½	15	—
Red lead .	—	—	—	—	19	—
Soda crystals	—	22	—	23½	16	—
China clay .	12	15	11	8	11	3
Chalk . .	18	17	11	15	13	—

Glaze.

Frit . .	52	47	74	60	70	59½
White lead	18	21	12	18	6	18½
Cornish stone	30	31	8	22	—	11
Feldspar .	—	—	—	—	23	—
Flint .	—	—	6	—	—	—
Chalk .	—	—	—	—	—	11

Preparation of Felspathic Bodies.—The raw materials which enter into the preparation of the bodies must be purified (if necessary) and ground.

The *clays* employed for faience are either in a natural state or have been washed ; this washing can be done at the pits or in the factory. It is necessary, as a general rule, to wash crude, coarse clays, employing the methods described on page 77 ; but the finer felspathic faience, such as English fine earthenware, is usually made of clays which are bought ready for use.

The *china clay* is washed in the course of its separation from the granite with which it is associated.

The *ball clay* is not washed, as it is sufficiently pure in its natural state.

The *white or buff-burning clays* used on the Continent for felspathic faience must usually be washed before they are fit to use.

The *flint* should be heated to redness, quenched, and ground before use, this being done either in the faience works, or in special works (p. 67).

The *felspar* and *Cornish stone* are sometimes ground chiefly in the faience works and sometimes near the quarries, or in works devoted solely to such grinding. The methods of grinding them have been described in Chapter IV.

In the preparation of the body, which is always converted into a liquid slip, it is necessary to mix each constituent separately with water and to separate any coarse particles by passing the slip through a fine gauze or lawn. To ensure the proper admixture of the solid matter with the water, it is usually necessary to employ blungers, mills with blocks or Alsing cylinders. When any limestone is required in the body it is generally ground and made into slip in the same manner as the flint. The usual method is to put into each machine a definite proportion by volume of the solid

material and water, then when the substance is entirely pulverized and completely mixed with the water, to run it out into one of four reservoirs. Each slip is then tested to see whether its consistency is correct. For this purpose, a certain specified volume (a pint, for example) is weighed. It is nearly always necessary to add a little more water to obtain the proper consistency; it is seldom that a thicker body contained in a special reservoir must be used to correct it.

In order that the subsequent mixing should be satisfactory, it is necessary that the four slips should be of about the same consistency, though they are not of the same density. The usual weights in England are :—

	Ounces per pint.	Grammes per litre.
Plastic clay (blue-ball clay)	24	1200
Kaolin (china clay)	26	1300
Silica (flint)	32	1600
Pegmatite (Cornish stone)	32	1600

The next step is to measure a suitable quantity of each of the four slips (each being of the required consistency), and to run them into a single tank or mixing ark.

Instead of measuring the quantity of each slip in a measuring vessel, it is usually more convenient to store the slips in rectangular tanks and measure the depth of the slip in inches, and as the area of the tank is constant, the volume of the slip is expressed by the depth in terms of "wet inches." Thus, if slips with the weights per pint just mentioned were to be used to make a body containing—

(Dry) ball clay	2 parts
(Dry) china clay	1 „
(Dry) flint	1 „
(Dry) Cornish stone	1 „

the proportion of each slip in "wet inches" may be found as follows :—

Divide the number of parts of each material required by its "weight per pint" less twenty, and multiply each result by a number to clear the fractions. Thus—

Ball clay	2 parts	$\div (24 - 20) = 2 \div 4 = \frac{1}{2}$	wet inch.
China clay	1 part	$\div (26 - 20) = 1 \div 6 = \frac{1}{6}$	„
Flint	1 „	$\div (32 - 20) = 1 \div 12 = \frac{1}{12}$	„
Stone	1 „	$\div (32 - 20) = 1 \div 12 = \frac{1}{12}$	„

To clear the fractions in this case, multiply each number by twelve, which gives :—

Ball clay	6 wet inches
China clay	2 „ „
Flint	1 „ inch
Stone	1 „ „

Conversely, to convert "wet inches" into dry "parts by weight," subtract twenty from each of the pint-weights and multiply the

number of wet inches by the result. Thus, in the example just given—

Ball clay . . .	6 wet inches	× (24 − 20) = 6 × 4 = 24	parts.
China clay . .	2 „ „	× (26 − 20) = 2 × 6 = 12	„
Flint . . .	1 „ inch	× (32 − 20) = 1 × 12 = 12	„
Stone . . .	1 „ „	× (32 − 20) = 1 × 12 = 12	„

W. J. Furnival, of Stone, Staffs, has published a set of tables which give, without calculation, the quantities in " wet inches " of slips of different weights per pint containing the same dry contents.

The contents of the mixing ark are thoroughly mixed, sifted once, twice, or even three times, through fine and finer sieves, and the product may then, if desired, be caused to pass through a magnetic trough (p. 89) to separate any particles of metallic iron. The mixed slip is then put into a filter press, and the cakes thus obtained are put in cellars and kneaded and wedged or pugged before being used for moulding.

Moulding Felspathic Faience.—The body, which is fairly plastic, may usually be shaped by any of the methods of moulding described in Chapter V ; throwing on the wheel or jolleying is generally used for making all-round objects for domestic purposes ; hand-moulding in plaster is used for other shapes ; and pressing is employed for paving-tiles.

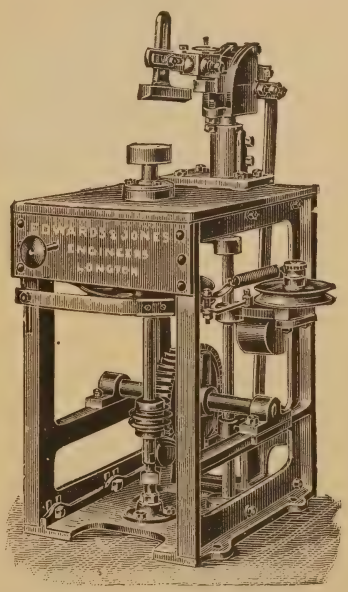


Fig. 262.—Bat-making machine.

In moulding flat or shaped pieces, dishes, plates, saucers, bowls, etc. (termed *flat ware*), are distinguished from taller goods or those contracted at the upper part (*hollow ware*). Flat ware is made by two operations : (*a*) throwing a bat ; and (*b*) moulding it on the jigger or jolley. Large objects are thrown on the head of a wheel working on the principle shown in Fig. 83. The profile may be worked by hand or automatically, as shown in Fig. 262. For this purpose, a lump or ball of body is placed on the wheel-head and the machine started. The profile descends, makes the " bat," and then rises again. The bat is removed and placed on a plaster mould similar in shape to the interior of the ware (Fig. 84), and another profile is lowered by hand, shapes the body, and with the mould gives it the desired form. Fig. 263 shows a machine of this kind. In some cases, the two preceding machines are placed side by side

in such a way that one moulder can work both. An arrangement of this description, shown in Fig. 264, allows of 500 pieces an hour being made.

The slabs can also be made on leather discs, stretched over a ring placed on the bed-plate or head of the machine. These discs are afterwards carried away with the shape and turned over on to

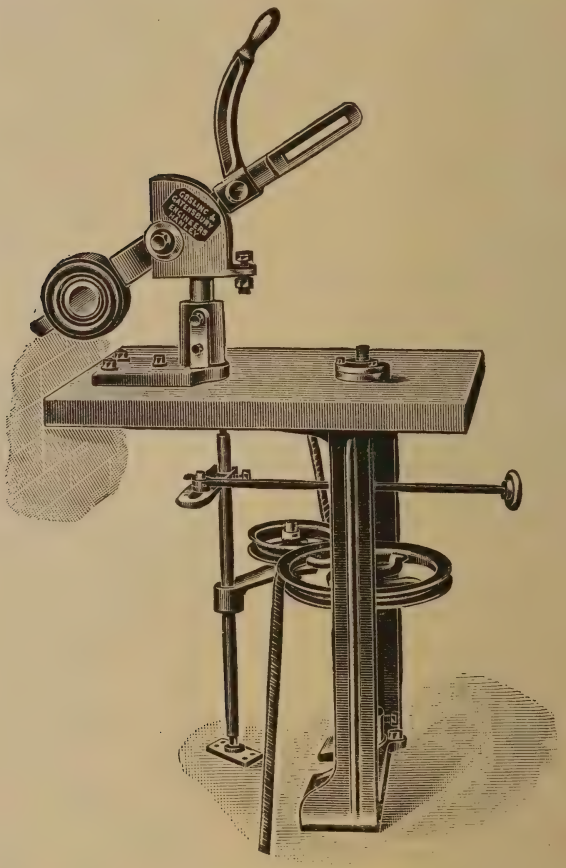


Fig. 263.—Jigger for flat ware.

the mould, a machine such as that shown in Fig. 265 being used, four moulds being placed on a carriage. Two of these moulds are centred on the bed-plates of two twin wheels, the profiles for which are moved automatically, while a workman takes away the manufactured articles from the other two and replaces them by "bats." When the moulding is finished, the workman pushes the carriage towards the left to allow of the finished pieces being taken away

Fig. 264.—Combined jigger and bat machine.

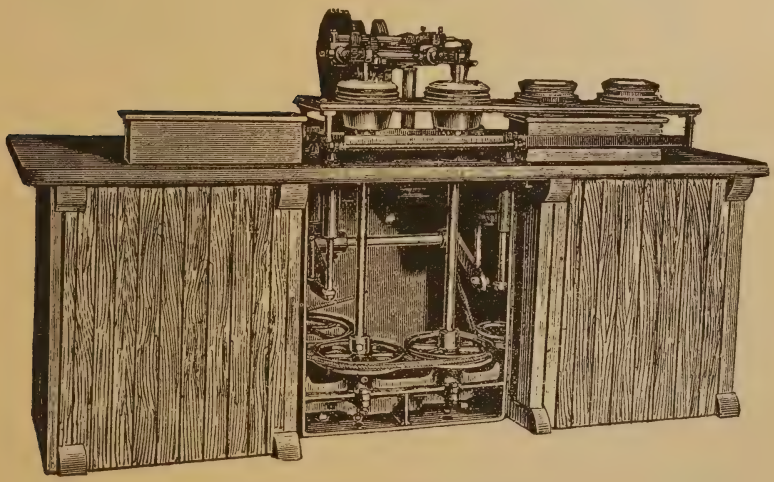


Fig. 265.—Double wheel for flat ware.

and new " bats " being placed, while the fashioning of the two new " bats " goes on. A machine of this kind will make 500 to 600 pieces an hour.

For making hollow goods, when the objects are not too large, the arrangement described on page 133 (Fig. 84) is used. Fig. 266 represents an automatic machine of this kind in which 500 articles an hour can be made. As soon as one cup is made and the profile raised, the mould is replaced by another containing a fresh " bat."

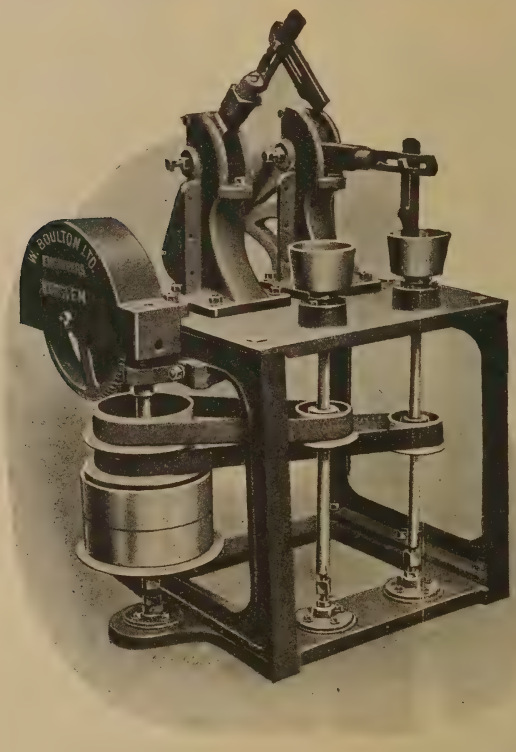


Fig. 266.—Twin jolley for cups, etc.

For wares of large size it is necessary to modify the process by making the body into roughly the desired shape (as by throwing) before putting it into the mould. The pivoted jigger is then replaced by one having a vertical motion, the profile—then termed a " plunger " —being fixed to a transverse arm, as shown in Fig. 81 (p. 132). Fig. 267 shows a machine of the same kind for very large objects ; if the latter have a narrow neck, the arrangement described on page 134 (Fig. 85) is used.

Paving tiles are often made of firm or even dry body in a press, the cake of body from the filter-press being dried either in the open air, on a heated surface, or else in a hot drying-room before being pressed. The dry body is then broken up coarsely by hand, and put into a pug-mill ; when necessary, the quantity of water needed to make it sufficiently moist is also added. The material passing out of the pug-mill falls into a centrifugal pulverizer, which reduces

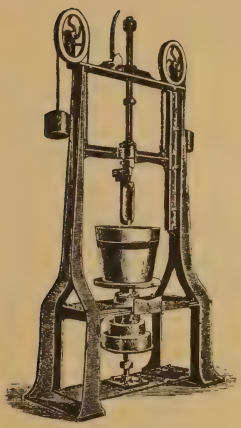


Fig. 267.—Jolley for large ware.

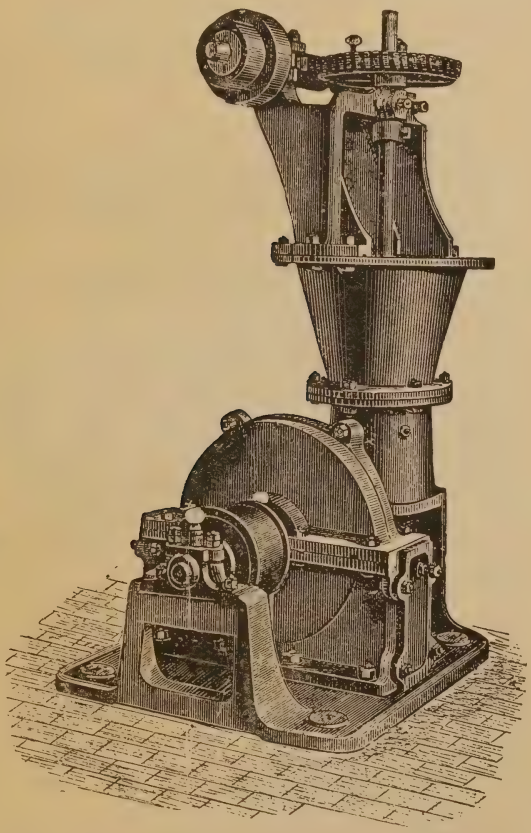


Fig. 268.—Centrifugal pulverizer or disintegrator.

it to a powder. These two operations may be done simultaneously in a disintegrator such as that shown in Fig. 268, which can produce 6 cwt. to 2 tons an hour, at an expenditure of 4 to 5 horse-power.

The powder is shaped under pressure in a metal mould or die by means of a machine with a fly-wheel. Figs. 90 and 269 show a press of this description in which the mould is emptied by raising the lower part of it by a lever or a pedal. These presses are made in

several patterns, according to the dimensions of the tiles, as shown in the following table :—

			Production per hour.
To press one paving tile,	2 inches diameter	. . .	250 to 320
„ two paving tiles,	2 „ „	. . .	300 „ 400
„ one paving tile,	4 „ „	. . .	150 „ 200
„ two paving tiles,	4 „ „	. . .	250 „ 300
„ one paving tile,	6 „ „	. . .	120 „ 140
„ „ „	8 „ „	. . .	100 „ 120
„ „ „	12 „ „	. . .	40 „ 60

For large quantities, power-driven friction presses are used (Fig. 91).

The processes of turning and also "casting," which are sometimes

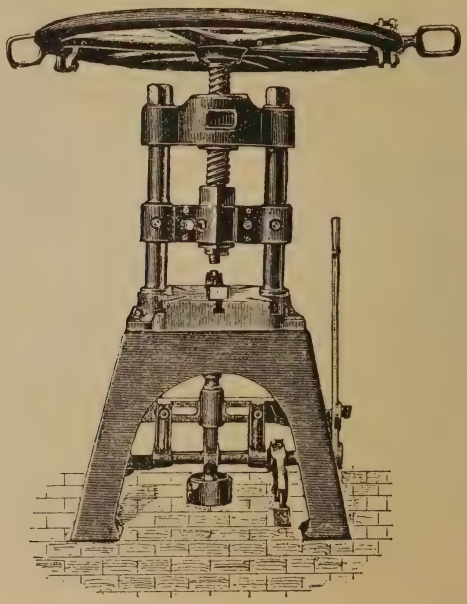


Fig. 269.—Screw press.

employed in faience potteries, are mentioned in Chapter XIV, as they are much used in the manufacture of porcelain.

Drying Felspathic Faience.—When the goods have been made in plaster moulds, they are left in them until they can be put into dryers. For this purpose, the moulds containing the articles are placed on boards over hot pipes in the moulding shops. In some works, drying-sheds heated by hot air, or by steam pipes, are used. In Chapter VI, pages 162 and 163 (Figs. 106 and 107), revolving dryers which are also used are described.

Artificial drying is indispensable in the moulding shops where

power-driven wheels are employed, or their large output would involve a vast increase of drying space which would be incompatible with the economical use of the motive power. In large potteries enclosed dryers are used as the most efficient drying requires a fairly intense heat, and this, if applied in the moulding shops, would soon cause the atmosphere of the workrooms to be charged with steam which would act in an injurious manner on the health of the work-people.

Burning Felspathic Faience.—For burning English fine earthenware, round up-draught kilns or ovens, surrounded by a cupola (or hovel) ending in a chimney (Fig. 270) are used. The cupola is for

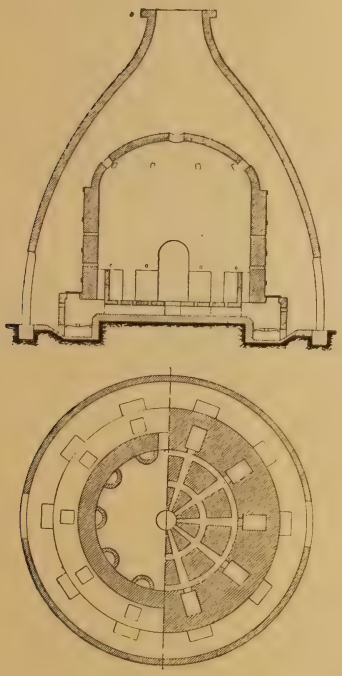


Fig. 270.—Hovel kiln.

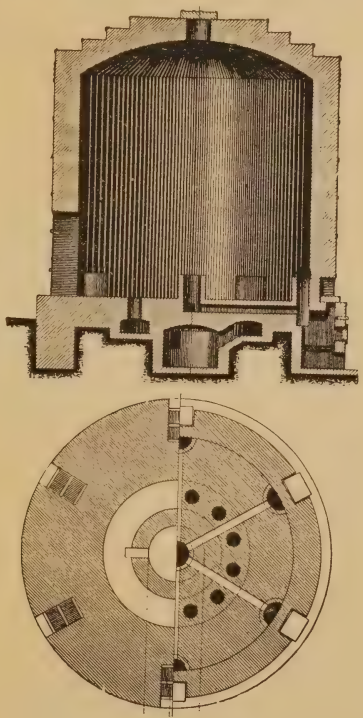


Fig. 271.—Earthenware kiln.

the double purpose of ensuring a draught and of isolating the kiln from the workrooms or, when the kiln is placed outside other buildings, to protect it from the weather. Potters on the Continent prefer round down-draught kilns, the draught being created by a separate chimney which may serve for several kilns. Fig. 271 represents a kiln of this kind. The fireboxes—six to ten in number—communicate with a central opening, so that the flames enter the kiln up the " bags " around the circumference and also up a central

"bag" or "well hole." The gases are carried off by a series of concentric openings in the floor of the kiln, which communicate with a circular receiver, connected by several flues to a central flue, which opens into the chimney. The diameter of these kilns varies from 11 to 20 ft., and the height from 13 to 23 ft.; the medium-sized ones give the best results.

The slow firing usually lasts from six to eight hours, and the hard firing from sixteen to twenty-four hours. The consumption of fuel —which varies greatly in the different potteries—may be reckoned at 6 lb. per cubic foot of the capacity of the kiln. It is advisable to lose as little space as possible in placing, as the quantity of fuel consumed remains almost the same, whatever the weight of the goods in the kiln.

The thermic balance sheet of a kiln of this description is, roughly :—

Heat produced by fuel . .	100	Heat theoretically necessary for the ware	17
		Heat lost in placing . . .	34
		Heat lost in heating the walls .	10
		Heat lost through the chimney .	25
		Heat lost by incomplete combustion	14
	100		100

For burning faience, continuous kilns (p. 226) heated by either coal or gas have also been employed; the results obtained are not always satisfactory, though for glazed tiles and much domestic pottery the Dressler tunnel kiln has proved satisfactory and very economical in fuel. In a well-designed continuous tunnel kiln only about one-third of the fuel needed for separate kilns is required, and the "placing" of the ware is greatly simplified, as it is laid on trucks instead of being packed in saggars.

In a continuous kiln in which the goods are stationary and the fire travels forward, about 30 per cent of the total heat produced by the fuel can be recovered, and the loss through the chimney reduced 5 to 10 per cent, but the losses due to heating the walls and by radiation would be increased, and it would be necessary to add to them the loss due to generating the gas if this is used. Thus a saving in fuel of 20 per cent or of most 30 per cent, would be all that could be attained. The workman's labour in "placing" is reduced, but is more than in a tunnel kiln.

Felspathic faience needs two heatings, the first at a temperature of about 1200° C. for burning the body, and the second at 1000° to 1100° C. for the glaze. These two heatings are usually done in succession in the same kilns, the latter using only 5 lb. to 6 lb. of coal per cubic foot of ware set in the kiln, but the quantity of ware it is possible to place at one time being smaller, the expenditure of fuel is really the same or even rather greater for the glaze than for the body.

Setting or Placing in Saggars.—Fine earthenware is always placed in saggars, these being piled on one another, leaving a space between the top saggar and the dome of the kiln. These piles of saggars are arranged concentrically, the outer row being placed at a short distance (3 to 6 in.) from the wall. The piles which compose it are put against one another in such a manner as to guide the flames towards the dome. The inside piles are also close together, but to allow of the circulation of the gases near the floor, the lowest saggers are placed on pedestals formed of fire-bricks. As saggars of different sizes have to be used, the workmen try to place the smaller

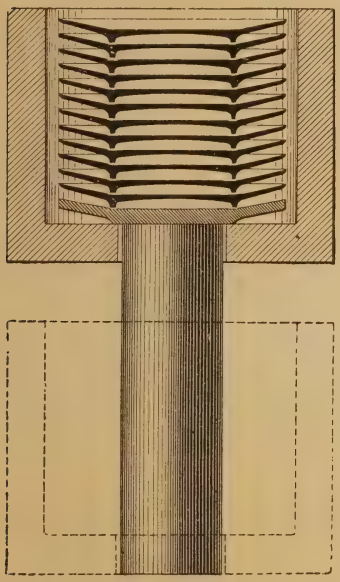


Fig. 272.—Filling a saggar with plates.

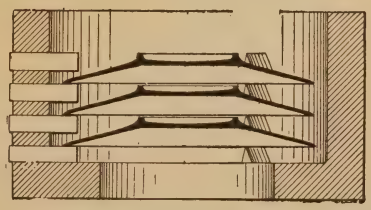


Fig. 273.—Use of head pins.

ones in the spaces left between the larger ones. This method of setting is suitable for down-draught kilns ; for up-draught kilns it is necessary to separate the piles, supporting them against each other by means of little pieces of fireclay put against the saggars.

The filling of the saggars with unglazed articles does not, as a general rule, offer any difficulty, because they can be piled up in a heap, and the workmen's chief concern is to place the largest possible number of articles in each saggar. For pieces like plates, which have a diameter so nearly equal to that of the saggar that it prevents their being put into the saggar by hand, the method shown in Fig. 272 is employed, i.e. a saggar with a central opening is placed on a bench and a cylinder of wood of rather smaller diameter than the opening is placed in the saggar. The plates, on a suitable fireclay support, are then placed on the wooden cylinder, and then, by raising the

saggar, the operation of filling it is completed. It is necessary not to overload the lower plates or they may break.

The filling of the saggars used for burning the glaze is much more difficult, because the glaze necessitates each piece of ware being separated from the others by small fireclay supports, leaving only a point or a small part in contact with the piece.

The following are some examples of the most usual arrangements :—

Fig. 273 shows a section of a saggar, into the walls of which are embedded small triangular pieces called *head pins*, which serve to

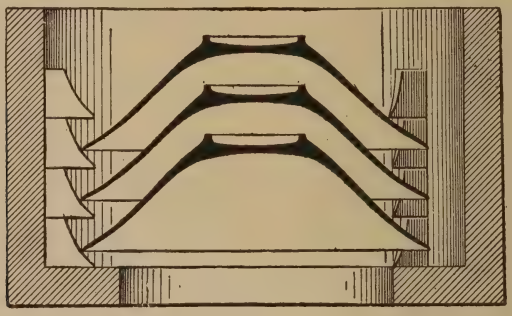


Fig. 274.—Use of bowl pins.

support the pieces of ware. For this purpose the saggars are pierced with triangular holes, which, when the head pins are in position, are filled up with a little fireclay paste. Contrary to what is shown in the drawing, these head pins are not placed vertically one above

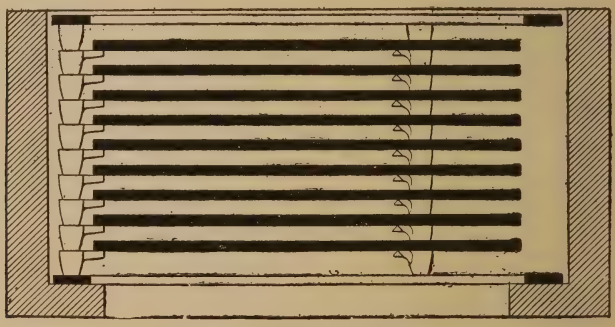


Fig. 275.—Use of thimbles.

another, but follow the line of a helix, so as not to weaken the saggar too much.

Instead of piercing holes in the saggars, *bowl pins* which are approximately of the shape of truncated or triangular pyramids, are piled on one another, along the walls, as shown in Fig. 274.

Thimbles or small hollow truncated cone-shaped pieces, fitting

into one another and having a small triangular projection, on which are placed the plates or tiles, as shown in Fig. 275, may also be used. In order to keep the thimbles in position, the three lowest thimbles are fastened permanently to a fireclay ring, and a similar ring with three projections is fitted into the top thimbles.

Instead of the pieces of ware resting on the saggars or on the

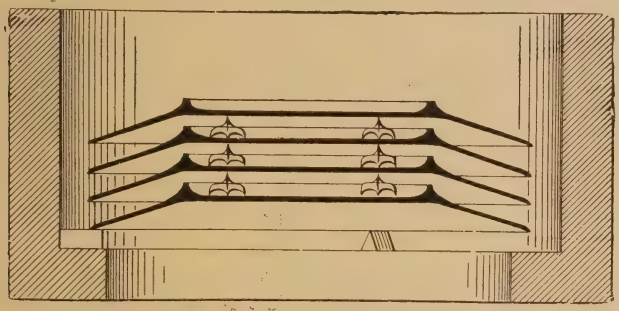


Fig. 276.—Use of cock-spurs.

supports just described, they may rest on one another by separating them by little triangular pieces having three lower points and one upper one, called *cock-spurs* (Fig. 276), or the pieces, especially plates, may be placed upright in rectangular or oval saggars, the pieces being kept upright by resting them on triangular strips or saddles, and holding the plates at the top by a series of thimbles as shown in Fig. 277.

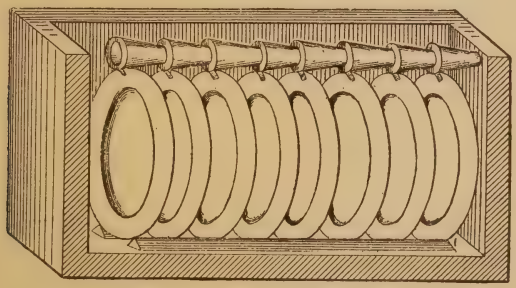


Fig. 277.—Use of saddles and thimbles.

The methods used depend entirely on the shape of the ware, and can be varied in details. All these " supports for burning " or *stilts* have separate names according to their shape : simple *pins*, cut-off pins, or pins with a top, simple or double *spurs*, stilts with three or six points, thimbles, *butterflies*, *easels*, etc., being used. These supports are made of fireclay, and are stamped out of a stiff body by means of small lever presses worked by hand. A machine

of this kind is shown in Fig. 278. It is usually best to buy them from firms who make a speciality of their production.

Decoration of Felspathic Faience.—All the methods of decoration described in Chapter IX can be used for felspathic faience.

The colourless glazes, the composition of which has already been given, are usually applied by dipping. They are sometimes tinted with a little cobalt oxide to neutralize the yellowish colour of the body.

Coloured slips (made by adding colouring matter to the body) are sometimes used for making backgrounds, and are then generally applied to the unburned body with a brush. The bands or borders on plates are formed by turning the ware on a wheel in front of a

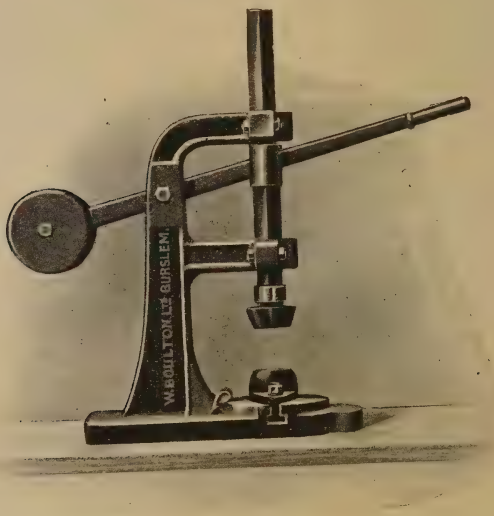


Fig. 278.—Press for small articles.

brush, which is kept in one position. As the proportions of the colouring materials which must be added are usually somewhat large, the composition of the body must be modified, so that the shrinkage may be the same as that of which the articles are made. This adjustment is usually made by adding lean clay or flint and correcting the diminution of the fusibility by a little felspar. The composition of the slips thus varies with that of the bodies, and it is impossible here to give more exact details on this subject.

Under-glaze colouring is the method of decoration chiefly used, especially for table-ware. Decoration by printing is now almost exclusively employed (p. 268), painting with a brush being only used for making bands or backgrounds or to lighten the designs obtained by monochrome printing.

The following are the most usual colours :—

Black.

(*a*)

Iron oxide	44
Lime	44
Manganese oxide	10
Cobalt oxide	2

(This mixture is burned, then washed and ground.)

(*b*)

Iron sulphate	65
Bichromate of potash	28
Manganese oxide	10
Cobalt oxide	6

(The first two substances are heated together, the others are added to them, then heated afresh, washed, and ground.)

Blue. I.

Cobalt oxide, in proportion varying with the depth of the colour, mixed with a little flint and carbonate of lime.

Blue. II.

Precipitated and well washed alumina	70
Nitre	10
Cobalt oxide	20

(Mix together, heat, and grind.)

Blue. III.

Ammoniacal alum	80
Zinc oxide	12
Cobalt oxide	8

(Heat, wash, and grind.)

Bluish-Green.

Flint	22
Borax	22
Zinc oxide	20
Chrome oxide	16
Cobalt oxide	8

(Frit together and grind.)

Green. I.

Flint	66
Borax	13
Chalk	1
Chrome oxide	20

(Melt a part of the flint with the borax, complete the mixture, heat it again, and grind the product.)

Green. II.

Flint	32
Borax	42
Zinc oxide	11
Chrome oxide	11
Cobalt oxide	4

(The same as above.)

Brown. I.

Iron sulphate	38
Zinc oxide	38
Bichromate of potash	24

(Heat, wash, and grind.)

Brown. II.

Iron chromate	50
Manganese oxide	50

Red.

Zinc oxide	50
Chalk	25
Flint	18
Bichromate of potash	3
Borax	4

(The following fluxes are added when heated.)

Red	70
Felspar	10
Borax	16
White lead	4

(The product is heated at a low temperature and then ground.)

Yellow. I.

Lead oxide	17
Tin oxide	66
Antimony oxide	17

(First calcine and then mix the oxide of antimony. For the deepest ground and orange, iron oxide is added.)

Yellow. II.

Lead oxide	41
Tin oxide	21
Antimony oxide	28
Iron oxide	10

Violet (unique).

Tin oxide	100
Boracic acid	10
Cobalt oxide	¼
Lead bichromate	1½

(Heat and add 20 per cent of white lead. For darker tones add more cobalt oxide.)

For decoration by printing, these powdered colours are added to the printing ink ; when put on with a brush, gum tragacanth or glycerine is added to them.

Coloured glazes are often used for decorating. They are composed of a colourless glaze, with the addition of colouring oxides, and sometimes with a little extra red lead, which increases the brilliancy of the colours, but makes them run easily. The colouring oxides are mixed in the proportion of 3 to 12 per cent, according to the shade desired. A coloured glaze may also be made by mixing the preceding under-glaze colours with it.

Faiences with under-glaze decoration or with coloured glazes are burned in saggars in ordinary kilns.

Over-glaze colouring may be used in the form of vitrifiable colours. This method—which is less employed for faience than for porcelain—is described in Chapter XIV.

General Arrangement of Faience Works.—In England, nearly all the fine earthenware works are situated in North Staffordshire, around the five towns now forming Stoke-on-Trent. In France, Germany, Belgium, and Austria the more important faience works were originally placed near the beds of plastic clay, and as near as possible to the coalfields, or in localities particularly favourable for cheap transport, but with improved facilities for the transport of raw materials ; some of them are now near the large centres of consumption.

These works are composed of buildings of two or more stories, on the ground floor of which are the workshops for the preparation of the bodies, the manufacture of the saggars and the muffles. The moulding and decorating shops are generally on the first and second floors ; the kilns are either outside or, what is more convenient, are placed in a large closed shed which communicates with the other buildings ; other, smaller sheds contain the supplies of raw materials and manufactured wares. A forge, workshop for repairs, pattern shop, warehouse, etc., are also necessary.

When a tunnel kiln is used, it may conveniently occupy the greater part of the ground floor of the building, and the shaping and decorating shops may be above it. The preparation of the materials is more conveniently effected in a separate building.

CHAPTER XIII.

STONEWARE.

STONEWARE (the French term for which is *Grès*) is an opaque, impermeable ware, with a coloured body, the predominating shades being slightly yellowish, greyish, or bluish. Its surface may be either dull or covered with glaze. The impermeability of the body distinguishes it from terra-cotta and earthenware (faience); its opacity makes it differ from porcelain.

Although the distinctive characteristics of stoneware are its impermeability and opacity, this distinction is not as simple as it looks, as these properties are not absolute, but only relative. The opacity is discussed in the chapter on porcelain, so that it is now only necessary to define "impermeability."

Complete impermeability exists in bodies in which the material exactly fills the volume occupied, as in good specimens of metals and glasses. This complete impermeability does not exist in pottery; as in all ceramic productions, even when completely vitrified, the density of the material is lower than that observed when the same material is reduced to a fine powder; the difference shows the proportion of the pores or voids.

Under normal conditions, the term "impermeability" implies that substances which possess this property cannot be penetrated by any liquid, but particularly by water. Strictly, there is a difference between the porosity of a substance and its permeability, the former relating to pores which may easily become filled with water, whereas the permeability is a measure of the extent to which a given volume of water will penetrate through the material and pass out at the other side.

As regards porosity, the weight of liquid which can be absorbed by a body depends on the condition of the experiment; pieces of porcelain and stoneware, when perfect, can be soaked indefinitely in water without increasing in weight, but by submitting them several times alternately to the vacuum produced by an air pump and to a considerable pressure of water, the pores can be filled with water. Even when simply immersed in water, wares which do not show any noticeable increase in weight at the end of some hours do show it after several months, and even porous wares increase indefinitely in weight on prolonged soaking, though the increase is slower after the first hour. Hence, the volume of water absorbed tends to correspond to the total volume of the pores, but never equals it.

A continuous series of wares can be arranged, passing insensibly from terra-cotta and faience to stoneware and porcelain, without it being possible at any point to trace the limit between porous or permeable and non-porous or impermeable ware. Arbitrary limits —fixed for the application of Custom House duties, for example, and based on a maximum amount of water absorbed by a ware under definite circumstances—can have only a roughly relative value.

From a ceramic point of view, it is convenient to reckon as stoneware all pottery which is opaque, has a vitrified body, and is almost devoid of porosity or permeability. It frequently happens that ware made with bodies suitable for stoneware is too porous to be reckoned commercially as stoneware, because the burning has not been carried to a high enough temperature, but, ceramically, such ware is none the less stoneware. Frequently this name (stoneware) is given to ware which is not strictly impermeable, but is sufficiently so for some purposes, e.g. sewerage pipes with a fireclay body which is relatively porous but has been made impermeable by a coating of salt glaze, and certain paving tiles, which are only slightly permeable and very hard. As these wares are manufactured by the same method as true stoneware they are treated as such in this chapter, though this classification is theoretically incorrect.

Brongniart and most other writers have divided stoneware into (1) common stoneware, the basis of the body being a vitrifiable clay and the glaze saline ; and (2) fine stoneware, having a body and glaze similar to those used for felspathic faiences. Fine stoneware, the manufacture of which has not been noticeably modified since Brongniart's time, has a composition which distinguishes it from the other kinds ; but common stoneware has been considerably developed, and certainly will become increasingly important in the future. It is no longer used merely for making jugs and pipes ; it will take glazes other than salt glaze, and may be decorated so effectively as to be classed amongst the most beautiful wares the ceramic art can produce. Under these conditions, the epithet of " common " has lost its meaning, and gives rise to the same errors and objections as the same term applied to earthenware. If, in the absence of any other term and on account of its being the one generally used, fine stoneware must still be designated by this name, it is desirable to suppress the adjective " common " for some other varieties and to consider them simply as " stoneware."

Stoneware Paving Tiles.

Stoneware tiles and others which are sold as such are of varied shapes, according to their different uses and to the variable quality of the body. For lining walls and for indoor pavements, square or hexagonal tiles are generally used (type I, Fig. 279), with sides 4 to 9 in. in length. The thickness varies from $\frac{1}{4}$ to $\frac{1}{2}$ in. Paving

tiles are usually of one colour : white, red, brown, black, or sometimes yellow, but tiles of different colours are used to form a pattern.

For paving footpaths, porches, stables, etc., plain or grooved square tiles are used (type II), with sides about 6 in. long, the tiles being 1 to $1\frac{1}{2}$ in. thick. They are of one colour : yellow, brown, red, or black.

For pavements subject to heavy wear, the tiles should be thicker, shapes similar to those shown in type III being generally adopted.

Paving tiles may be decorated with coloured slips applied by

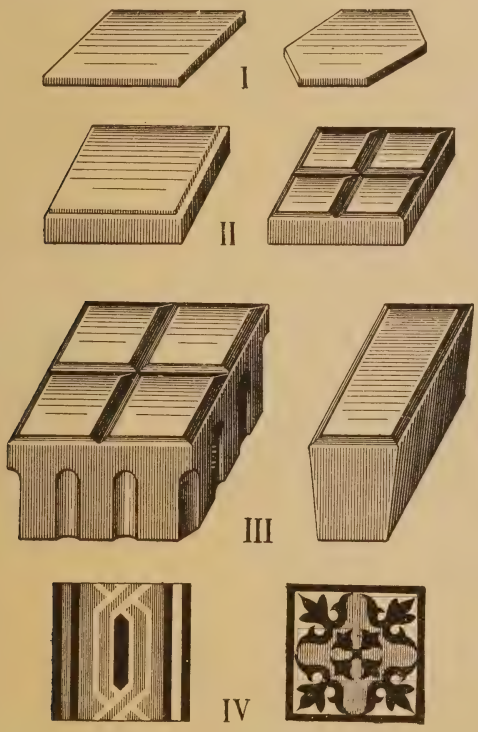


Fig. 279.—Paving tiles.

in-laying, as shown in type IV. The tiles are then generally 4 or 6 in. square, but may be of other shapes. The thickness varies from $\frac{1}{2}$ to $\frac{3}{4}$ in.

The composition of the body varies : in some works a vitrifiable clay is used ; in others, a fusible clay is made more refractory by adding fireclay, or a fireclay is made vitrifiable by the addition of flux.

Vitrifiable clays would melt to a glassy mass in a porcelain kiln, but they remain dull in earthenware kilns. A clay is regarded as

vitrifiable if, when heated to a temperature of about 1200° C., the product is practically devoid of porosity. This is due to the pores in the material being filled with a molten glass or slag-like material formed by the action of heat on the more fusible constituents of the clay. They contain a notable proportion of fluxes, chiefly alkalies, lime, and iron oxide ; this last is nearly always in the form of ferric oxide (Fe_2O_3), and consequently can only act as a flux by burning in a reducing atmosphere, which turns it into the form of ferrous oxide (FeO). Hence all vitrifiable clays containing iron are more fusible when the burning is in a reducing atmosphere than when in an oxidizing one. In the latter case, only the alkalies, lime, and magnesia can be relied on to cause vitrification. The proportion of lime and magnesia is not usually high, being seldom above 2 per cent. The amount of alkali, on the contrary, is seldom below 3 per cent, and may be as high as 6 per cent. According to Vogt, the alkalies are in the form of extremely fine particles of mica.

There is a wide difference between the behaviour of lime and alkalies, for the lime, at the moment the temperature for decomposing the carbonates is reached, tends to form a double silicate of alumina and lime, perhaps also some lime aluminate ; the product is a very mobile fluid which rapidly permeates the whole mass and separates the less fusible particles, so that, in spite of the silicious " skeleton," the mass softens shortly after it begins to vitrify, and the ware quickly gets out of shape. With alkalies in the form of mica or felspar, on the contrary, the vitrification commences with the fusion of these rocks, and the little grains of flux enter very slowly into combination with the silica and alumina surrounding them, so that there is a fairly long interval between the commencement of the vitrification and the moment at which the article loses its shape.

Vitrifiable clays are usually plastic ; the proportion of alumina varying between 25 and 30 per cent. The lime, magnesia, and alkalies, being in an impalpable state in the whole mass, may cause it to soften and warp as soon as it vitrifies, so that it is generally necessary to add a suitable proportion of silica or fireclay to the body to serve as a stiffener and to allow the material to become vitrified, i.e. non-porous without the goods losing their shape. It will easily be realized that if a mixture of equal parts of glass and some infusible material is heated until the glass melts, the mass would lose its shape, but if the proportion of glass were sufficiently small the grains of infusible material might be sufficiently firm to enable the shape to be retained. If the molten glass were very fluid, the loss of shape would be much greater than a highly viscous glass ; hence it is important to avoid too large a proportion of alkalies or lime which produce mobile glazes, whereas ferrous oxide and magnesia produce more viscous ones. From a consideration of the proportions of " glass " and " infusible matter," it will be realized that the coarseness of the grains of silica is of very great importance : if too fine, they melt too rapidly when the body fuses ; if too large, they prevent

it from becoming impermeable. The composition of stoneware bodies made of vitrifiable clays can only vary between narrow limits.

The following are average proportions :—

Silica	68 to 75 per cent.
Alumina	20 „ 25 „
Lime and magnesia	2 „ 12 „
Alkalies	3 „ 5 „

If iron oxide is present it may reach as high a proportion as 15 per cent. As natural vitrifiable clays which do not lose their shape too readily are comparatively rare, it is customary to use various mixtures which will have the desired properties.

A mixture of fusible clays and refractory materials may be used to form a vitrifiable body similar to the preceding ones, though, as fusible clays usually contain much more lime than alkali, the vitrification occurs at a distinctly lower temperature.

For bodies of this description, the proportion of alkalies seldom exceeds 2 per cent, while that of the lime is 6 to 10 per cent, the amount of silica being 68 to 75 per cent, and the alumina 20 to 25 per cent, although the relative plasticity of the calcium carbonate would allow of less clayey (i.e. less aluminous) bodies being used.

A mixture of fireclay and fluxes.—The forms in which the fluxes are added to a fireclay are as various as the proportion of them, because the latter depends upon the coarseness of their grains. The mixture which gives the best results is made by the addition of finely powdered felspar or Cornish stone. With a body of the same composition as vitrifiable clays with 5 to 6 per cent of alkalies, stoneware of a very good quality that will resist high temperatures for a very long time without losing shape can be obtained, because the fluxes are in a coarser form, whatever the fineness to which they are powdered, than those in the natural clays. Unfortunately, this method is rather costly for goods which are not of a high commercial value.

Alkalies may also be employed in the form of salts, but the vitrification then takes place at a low temperature, and has almost the same disadvantages as when lime is used. For economical reasons, calcareous fluxes are very much used, calcareous clay, marl, and limestone being used, but the substance which has given the best results is blast-furnace slag, which is an impure calcium silicate.

Bodies made of a mixture of fireclay and fluxes have somewhat the following composition :—

Silica	51 to 55 per cent.
Alumina	19 „ 22 „
Lime	22 „ 25 „

plus a small quantity of iron oxide, manganese oxide, magnesia, and alkalies. Tiles made with such bodies are always slightly porous, as they can only be heated to the commencement of vitrification without risking a sudden loss of shape. Even when overheated,

such a body does not become impermeable, so that, ceramically, these wares are terra-cotta rather than stoneware.

Sometimes fireclays are mixed with coarsely broken glass ; the body, when burned, is not then homogeneous, but is composed of refractory particles united by vitrified particles. Even if the heating were carried to the fusing point of the glass, the material would remain heterogeneous, and pieces of clay and silica would be found incorporated in the vitreous flux. Glass cannot be used in a very fine powder, because the loss of shape would then take place at the same time as vitrification.

The *pyrogranite tiles* manufactured in Russia are composed of a fireclay mixed with a fusible clay, the burning of which is carried on to the softening point in fireclay moulds. These wares have a wonderful polish, imitating that of hard stones, which is produced by passing them through a polishing mill. The introduction of grains of terra-cotta of different colours produces an imitation of granite.

Colouring.—In the chapter on burning (p. 193) the general part played by iron oxide in the colouring of bodies was described, but it is necessary to complete what was said by some observations peculiar to stoneware.

The colouring of stoneware is very variable ; though sometimes only slightly yellowish or bluish, it is frequently of a bluish-grey (pearl grey), darker or lighter yellow, red, brown, or black. Except in the very rare cases in which the body contains manganese oxide, these colours are due to iron oxide and to the way in which they are fired.

White can only be produced by using vitrifiable clays containing very little iron ; these clays are extremely rare, for, as already observed, a minute proportion of iron at the moment of vitrification is sufficient to colour the body. Generally, white stonewares are obtained by using a mixture of white fireclay, china clay, and alkaline fluxes, or of china clay, ball clay, felspar, and flint.

As in terra-cotta, the grey or bluish-grey colours are formed in a body containing a little iron, burned in a reducing atmosphere at a temperature above 800° C.

Yellow colours are produced in a body containing a little iron, or in calcareous ferruginous bodies heated in an oxidizing fire during the whole of the burning process. Under similar circumstances, bodies which are ferruginous and almost devoid of lime become brown or even black when the proportion of iron is high. A decidedly red colour is much more difficult to obtain in stoneware than in terra-cotta, for the body must contain much iron peroxide, little alkali, and no lime, and the burning—which must naturally be in an oxidizing atmosphere—must be stopped as soon as vitrification begins, or an unpleasant brown colour will be produced.

A uniform black can, in the absence of manganese oxide, only be produced by a reducing atmosphere, and by the formation of a deposit of carbon in the pores of the ware before it vitrifies ; the

ordinary method used for the manufacture of black tiles can scarcely be used, because it would be difficult to keep a suitable atmosphere above 800° C. up to the time of vitrifying. Hence, the ware should be enclosed in saggars filled with powdered charcoal or coke (p. 335).

Methods of Manufacture.—Stoneware tiles may be manufactured by two processes, by moulding the body (1) in a plastic state, or (2) as a moist or dry powder. In the first case, the process previously described for terra-cotta paving tiles (p. 335) may be used, the tiles being re-pressed when they have been sufficiently dried, in order to reduce the spaces in the body as much as possible. This process,

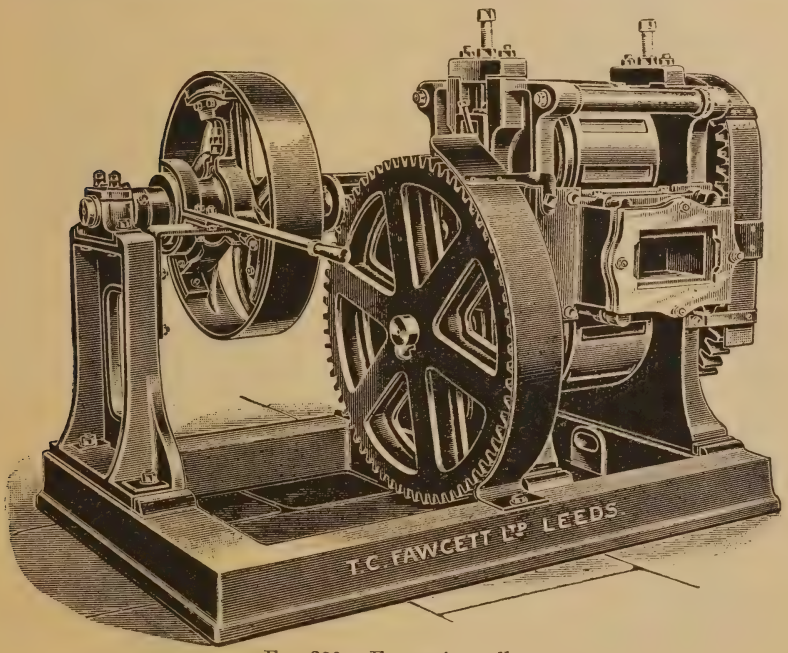


Fig. 280.—Expression rolls.

which need not be described at greater length, can only be used to make fairly thick tiles of a relatively low quality.

In order to make very thin and very hard tiles, moulding in plastic clay may be employed.

Thicker tiles, intended principally for paving, are pressed from a moist or dry powder as described later.

All the tiles just mentioned are of one colour throughout. Tiles ornamented with polychrome designs (inlaid tiles) are made almost exclusively from dry body reduced to powder and variously coloured (see p. 420).

Manufacture in Plastic Body.—The bodies used for this method of manufacture are generally plastic and contain alkaline fluxes.

White vitrifiable clays are used for white tiles, ferruginous tiles for red or brown ones. Black tiles are coloured either by manganese, or more often are burned in a saggar containing carbon.

The body is prepared as a soft paste, and is roughly shaped by forcing it through a die by means of expression rolls (Figs. 280 and 281). The paste, on coming out of the die, is received on a fixed cutting table (Fig. 282) and passes under a roller, on the two sides of which are stretched vertical wires, which cut it to the required

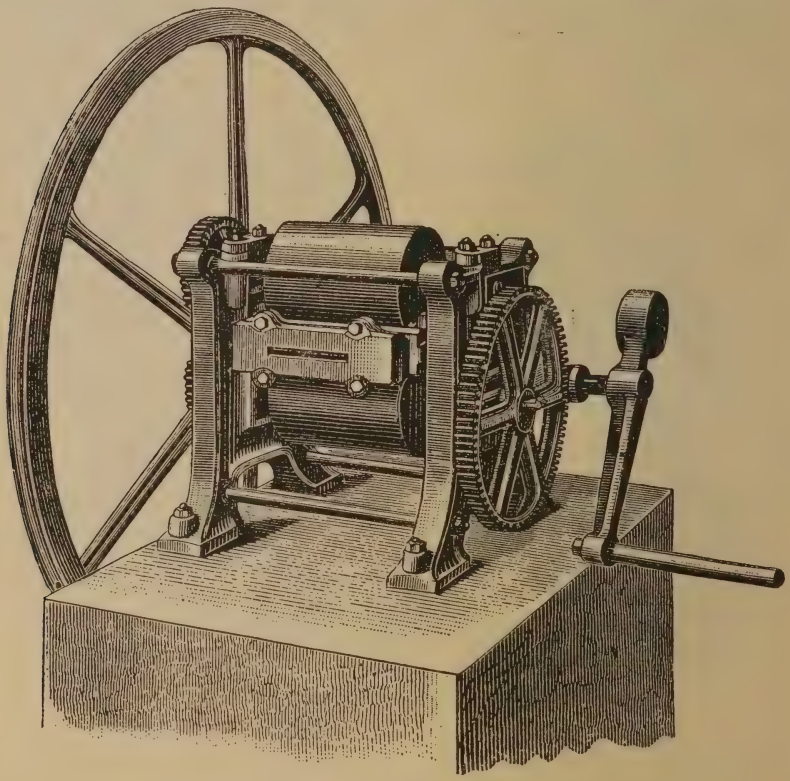


Fig. 281.—Expression rolls (hand-driven).

width. The lengthway cut is made by a series of transverse wires, as in the similar apparatus already described. The tiles, thus cut, pass under a second roller, in order to smooth out the ridges caused by the cutting wires. Hexagonal tiles are cut on a special table with bands of the width desired, and a special cutting frame, such as that shown in Fig. 283, is used. The cut tiles are then piled up until they have acquired the consistency of a firm body.

When the body is not naturally of the required colour, or when it is not of the desired intensity, it is dipped in slip. This slip dries

rapidly and the tile is then placed on a marble slab and struck on both faces with a wooden bat, after which the tile is put between two rolls (Fig. 284), the lower of which is grooved and the upper

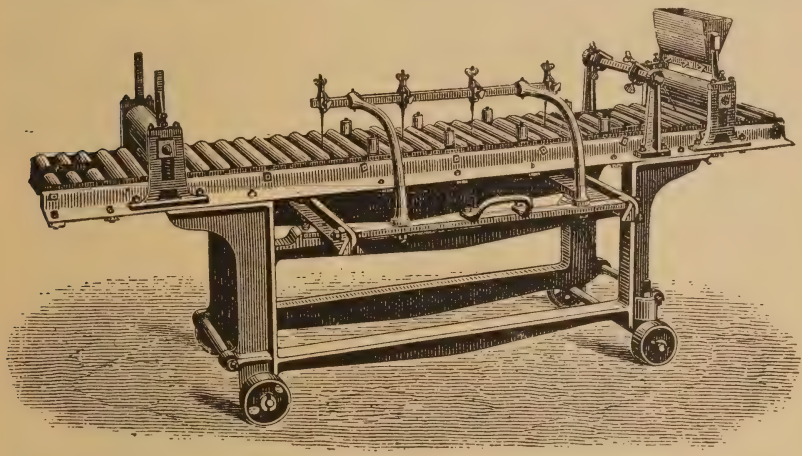


Fig. 282.—Cutting-table for floor-tiles.

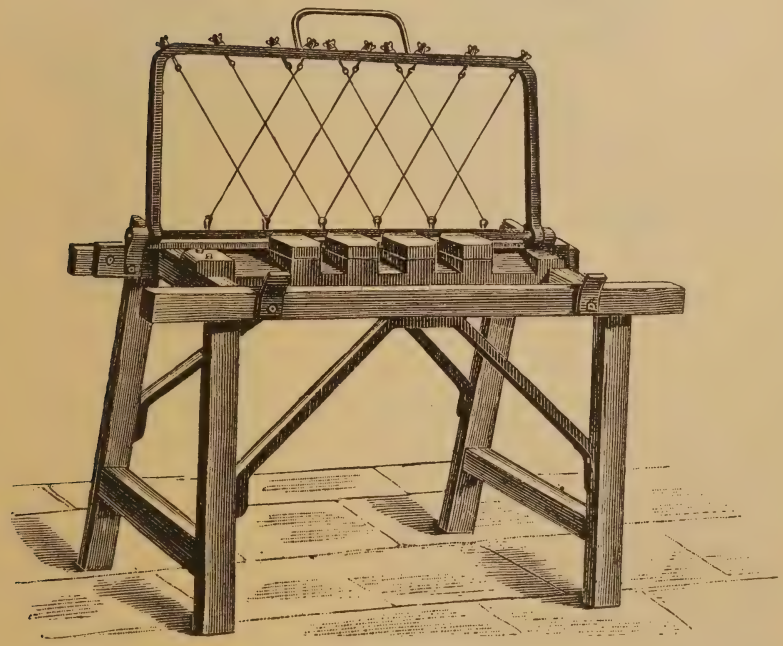


Fig. 283.—Cutting-table for tiles.

made of polished bronze. This machine indents the lower face of the tile, so as to make it adhere more easily to the bed of mortar, and polishes the upper face. To give the tile a regular shape, templets, or a special machine (Fig. 285), can be used. In the latter, a descending plunger cuts the edges obliquely and then opens out, so as not to carry up the tile as it ascends. The output of such a machine is 200 to 300 tiles per hour. The finished tiles are put in piles to complete the drying. The method of moulding just described is that suitable for best tiles ; it can sometimes be simplified, but at the expense of the quality of the goods.

Small quantities of tiles are burned in intermittent muffle kilns

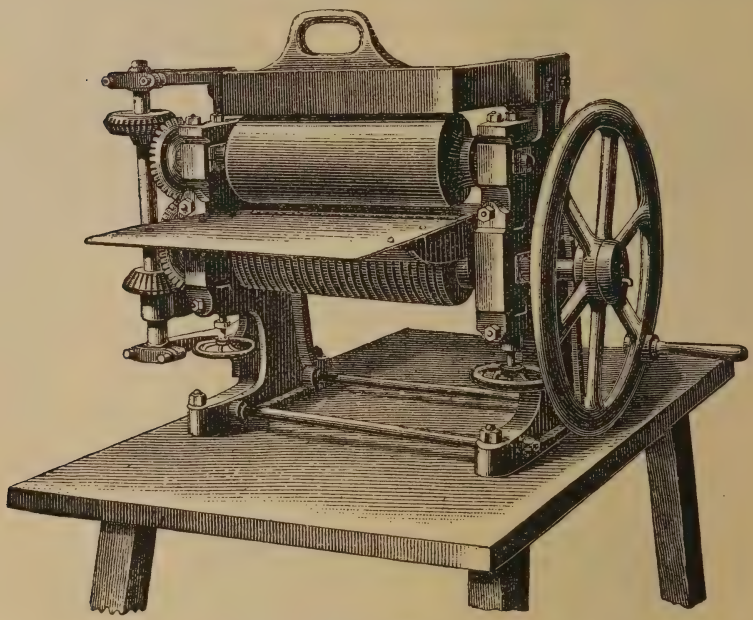


Fig. 284.—Tile-polishing machine.

of the type shown in Fig. 164 ; for large quantities it is better to use kilns heated by gas (Fig. 244). Whatever the type of kiln used, it is essential to have a very slow and careful preheating (p. 240), by means of special fireplaces.

The tiles are very liable to twist or warp during the burning, in consequence of the great shrinkage which takes place. The tiles are placed in the kilns in " bungs," which sometimes fall over if the heat is not uniform. This defect often necessitates the use of special devices for supporting them.

This method of manufacturing vitrified tiles is one of the most difficult met with in pottery, and needs extreme care.

Manufacture in dry body is much simpler than the preceding one, but does not allow such thin goods to be made. It is, however, particularly suitable for paving tiles. All the bodies and methods of colouring previously described may be used.

The raw materials must be dry, though certain substances, such as felspar and Cornish stone, are ground in water (by preference in block machines, or in Alsing cylinders) and dried before use. The ground body is moulded by powerful hydraulic presses, generally

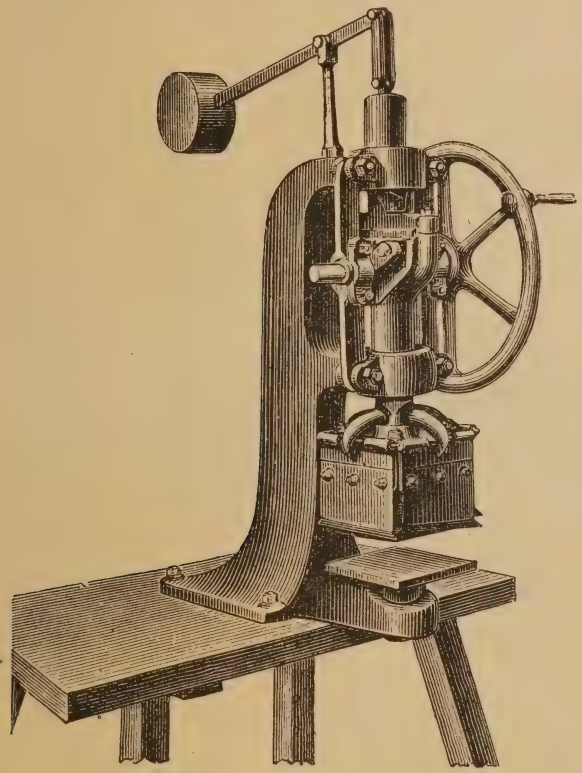


Fig. 285.—Tile-trimming machine.

in the following manner: The body (in powder) is put into the mould, a little pressure is then applied, either by hand or mechanically, after which the mould is placed in the hydraulic press. At first a low pressure is applied, after which the compressed air in the body is allowed to escape, and this treatment is followed by a high pressure. The mould is then drawn away, and placed on an apparatus for emptying it, which generally consists of a second hydraulic press, in which the water which served for the high pressure is used.

For small quantities, two moulds on a slide, which are placed alternately under the press and emptied, can be used, but the ordinary arrangement consists in placing the moulds on a revolving table (Fig. 286).

The tiles, when taken from the mould, are hard enough to be handled. They are then placed in drying-sheds, usually heated by waste heat from the kilns, but may also be taken direct to the kilns.

The tiles are placed in the kilns in bulk, being piled up to a height of 6 to 10 ft.; if piled higher, the lower rows would be crushed, when they begin to vitrify, by the weight of the upper ones. Black

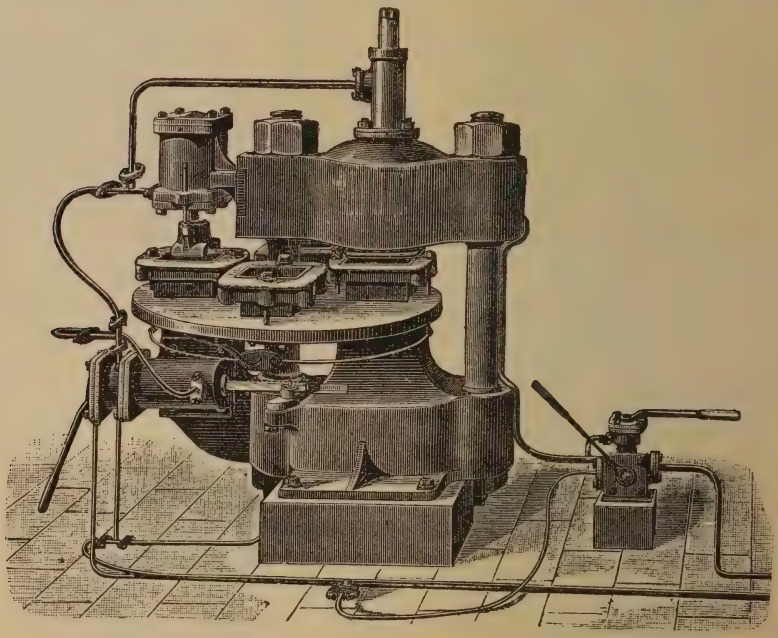


Fig. 286.—Hydraulic press for tiles.

tiles should be placed in saggars filled with carbon, as already stated, these saggars being placed in the middle of the other goods.

Small quantities are burned in round intermittent down-draught kilns, similar to those employed for burning fireclay goods, but less in height. The heat given off from the kilns when they are cooling may be used in the drying-sheds.

Where the output is sufficiently large, it is more advantageous to use continuous kilns. For this purpose, kilns of the original Hoffmann type have been used, but in spite of the expenditure of fuel being greater, it is better to use continuous kilns with chambers and fire-boxes. A gas-fired kiln is much easier to regulate, and is to be preferred. Fig. 287 shows a kiln of this kind (Mendheim)

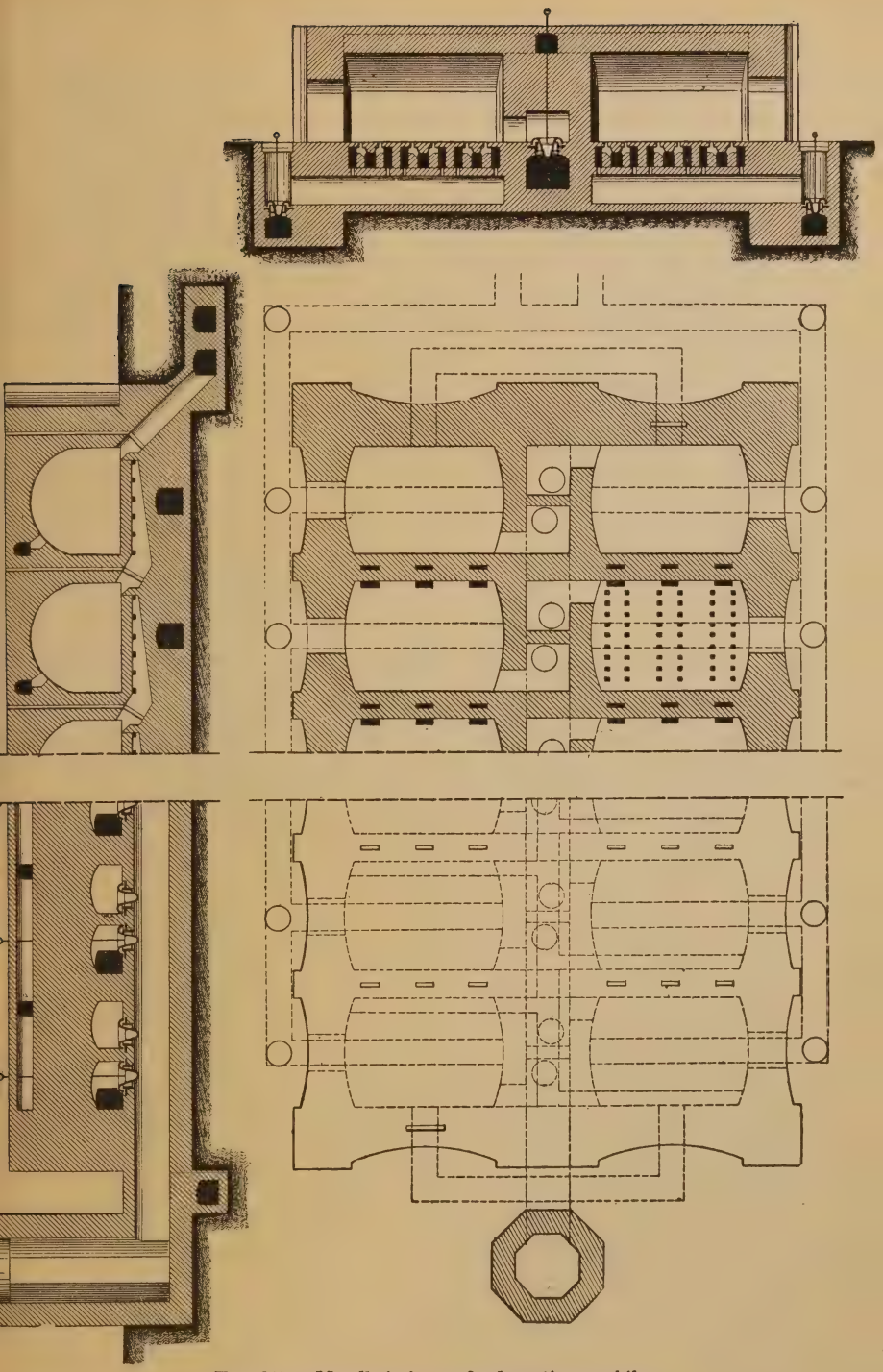


Fig. 287.—Mendheim's gas-fired continuous kiln.

made on the principle indicated by Fig. 160. Each chamber communicates with the following one by flues, starting at one corner, going underneath the floor, and ending in the next chamber. In the floor are also gas-flues placed parallel to the air-passages, so that the flames come up through a series of openings at the bottom. The gas is led into each chamber through an outside underground flue while the draught is caused by a central chimney.

Openings arranged in the walls separating the chambers allow fireproof dampers to be used, and flues placed along the arches serve for preheating with warm air (p. 307), as for burning bricks.

When they come out of the kiln, the tiles must be sorted, as two or even three qualities are produced, owing to irregularities in the burning.

The manufacture of these tiles needs large works to be remunerative; it is only exceptionally that they are made in other tile and faience potteries.

Inlaid tiles or encaustic dust tiles have been made since 1861. The body may be a vitrifiable clay or a mixture of fireclay and felspar, and, when necessary, silica. It is decorated by means of slips, applied in the form of a powder. The tiles are generally square, with a side of 4 to 8 in., the usual size being 6 in.: the thickness varies from $\frac{3}{4}$ to $\frac{3}{16}$ in. Half- and quarter-tiles are made, the latter being divided either rectangularly or on the diagonal. Borders have a rectangular form.

Fig. 288.

The slips are made by mixing a colouring oxide with the body (see p. 259). Naturally, the proportion of flux in the clay must be modified according to the fusibility of the colouring oxide. The slip is usually made a little more fusible than the body; it must be dried and ground to dust before use.

The application of the slip-dust at the time of making the tile is the distinctive and original feature of this manufacture. A templet—a little piece from $\frac{1}{16}$ to $\frac{1}{25}$ in. thick, formed of bands of copper soldered together, forming cells having the shape of the outline of the design (Fig. 288)—is passed to a series of workpeople, who each put a slip-dust of a definite colour into the proper cells. When the templet has been filled it is placed in the bottom of the press-box, a slight pressure is given to it, and the mould is then filled with ordinary body, the whole being afterwards compressed in a hydraulic press such as that shown in Fig. 289. In the front is a table, along which the moulds move. These moulds are formed of two pieces, one on the other, the lower being the thickness of the slip, and the upper that of the body. On the front of this table, the slips are put into the lower part of the mould, as just

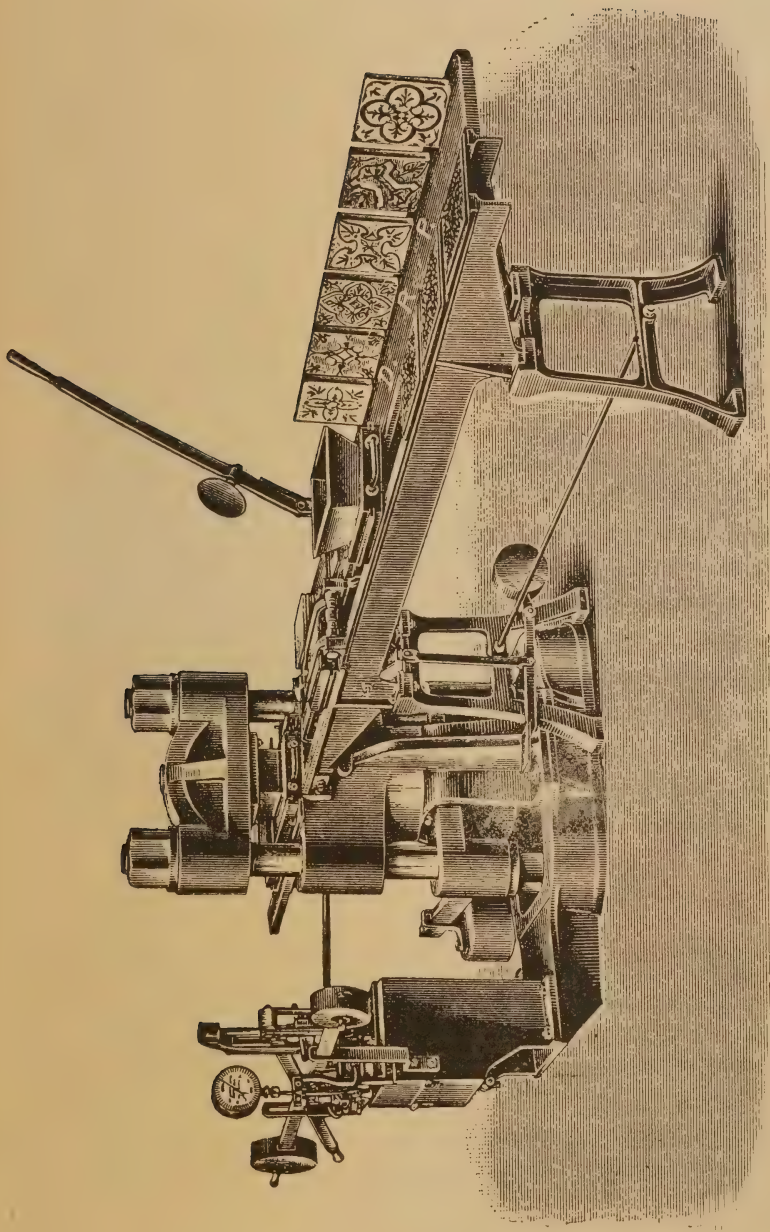


Fig. 289.—Hydraulic press for encaustic tiles.

described, then the upper part of the mould is put on, and filled with the body by means of a funnel; the mould is covered with a piece of cast-iron or steel, and the whole is pushed under the hydraulic press.

For larger quantities, a circular table is preferred along which movable moulds run on rails (Fig. 290). The moulds are filled by girls seated round the circular table; the whole working of the moulds and presses being attended to by a workman placed in the centre.

Inlaid tiles are dried in the same manner as smooth tiles, but the burning should be in saggars, in which the tiles are placed in

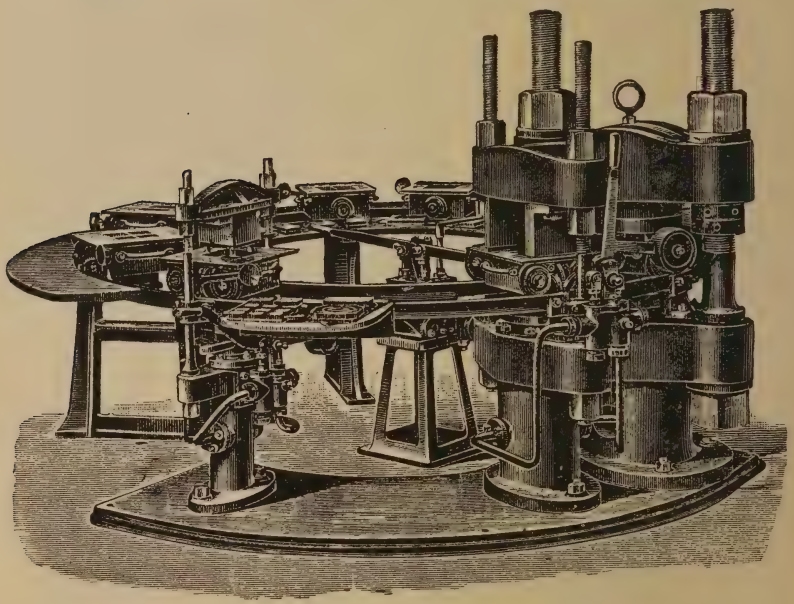


Fig. 290.—Hydraulic press for encaustic tiles.

bulk. Round down-draught kilns are generally used, but for large quantities continuous kilns can also be employed.

Tests for paving tiles are of two kinds: *Porosity* may be ascertained by first drying the tile at 110° C., immersing it in water, and measuring the increase of weight at the end of twenty-four hours. This increase is afterwards calculated as a percentage on the weight or volume of the dry tile.

The determination of the *resistance to wear* is the most important test (see p. 352). Tiles of true stoneware, when well made, offer a resistance to wear quite equal to that of the hardest natural stones.

Pipes.

Fig. 291 represents the usual forms of stoneware pipes, elbows, junctions, syphons, etc., employed in forming drains. The inside diameter may vary from 2 in. to 40 in., but those above 24 in. are seldom used. The length of the straight pipes varies from 18 in. to 40 in.

Such pipes are best made of a mixture of sand and vitrifiable clay, or of fireclay and felspar or Cornish stone, though a very large proportion of the drain pipes in this country are made of a low grade or "bastard" fireclay. It is much better, however, to use a more vitrifiable material, so as to produce an almost perfect stoneware—very impermeable and resisting great pressure—the only defect being a slight brittleness.

For reasons of economy, the felspar or Cornish stone are sometimes replaced by a limestone flux, i.e. a certain proportion of a

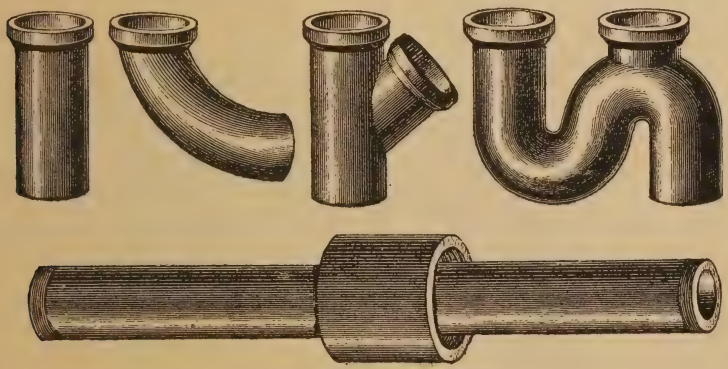


Fig. 291.—Stoneware pipes.

fusible calcareous clay is mixed with a slightly vitrifiable clay or with a fireclay.

Fireclays are excellent for pipes which retain their shape well, but the body of such pipes (apart from the glaze) is porous, and should not be considered as stoneware, though if a sufficiently low-grade fireclay is used containing various fluxes as impurities, an almost impermeable body may be produced.

The great advantage of making pipes with a non-porous, stoneware body is that if the glaze is imperfect or is damaged, the pipe will remain impermeable, whereas the imperviousness of a pipe with a porous body depends wholly on the glaze. In some works, the body is covered with a slip made of fine vitrifiable body; this increases its impermeability, improves its colour, and may enable the glaze to adhere better and to be more glossy.

Shaping.—Pipes are almost always made of a plastic paste, which is prepared in the same manner as that used for firebricks, the clays being ground to powder, screened, and then mixed with

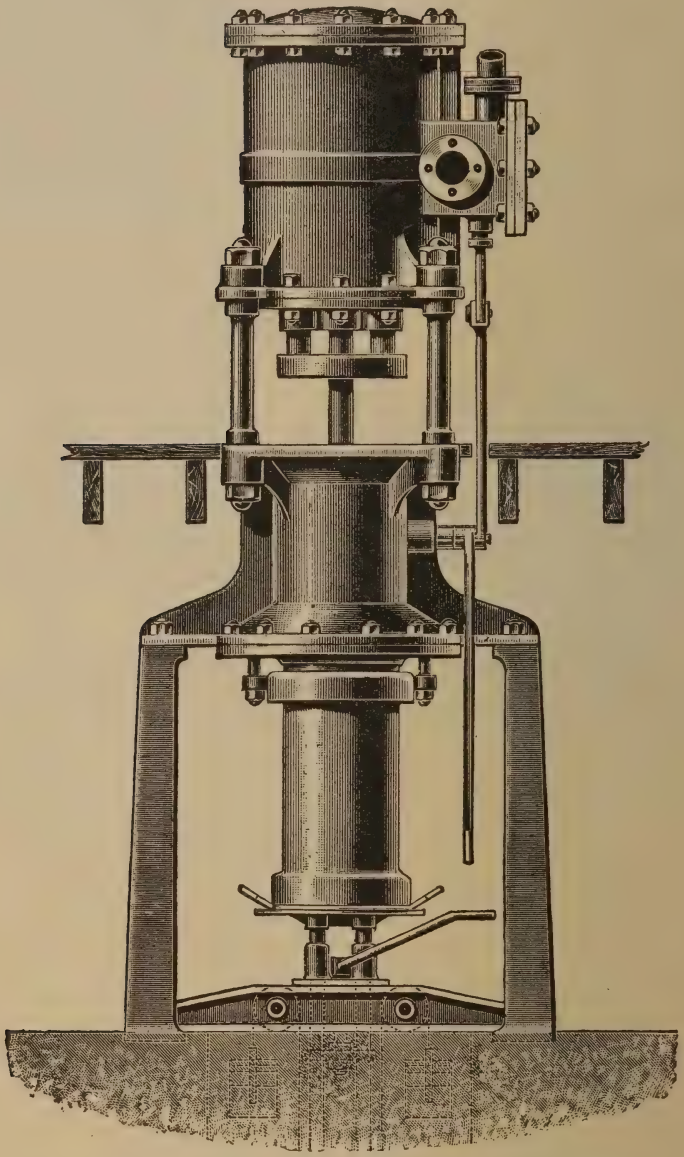


Fig. 292.—Pipe press with direct steam-pressure.

water in a pug-mill. The paste is usually improved by *souring* (p. 90) before being shaped.

Straight pipes may be made in three ways: (1) on the potter's wheel; (2) by expressing the pipes and afterwards attaching the socket by hand, this socket also being made of a portion of a pipe similarly drawn, but of a larger diameter; (3) by expressing the pipes, the socket being made simultaneously.

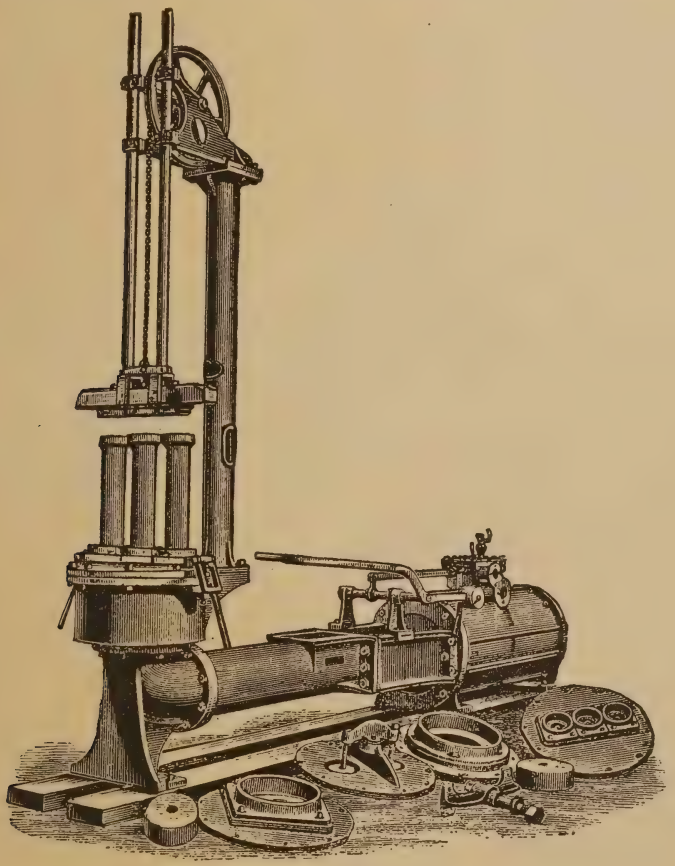


Fig. 293.—Pipe-press with upward pressure.

The first method produces pipes that do not look so well, in spite of the skill of the potter, and is costly. The second is only suitable for making small quantities, the joints needing to be carefully made. The third method is the one employed in all important factories. As it is essential that the goods should not get out of shape by their own weight, which might easily happen in the larger sizes, the pressing must be done vertically. The body, on coming

out of a circular die, strikes against a cap, the shape of the socket; owing to its plasticity, the body bends round the cap and, when it has become of the desired shape, the cap is released and the pressing of the straight part is accomplished as in other machines. When the pipe has reached the desired length, the machine is stopped, the pipe is cut with a wire, raised with the little board on which it rests, and is turned over so as to enable the cap to be taken away. Fig. 65 represents a machine of this kind in which the body is compressed in a cylinder by means of a belt-driven machine.

Sometimes the piston propeller, which forces the clay through the die, is set in motion by the direct action of steam. Fig. 292 represents a machine of this description, made by the Brightside

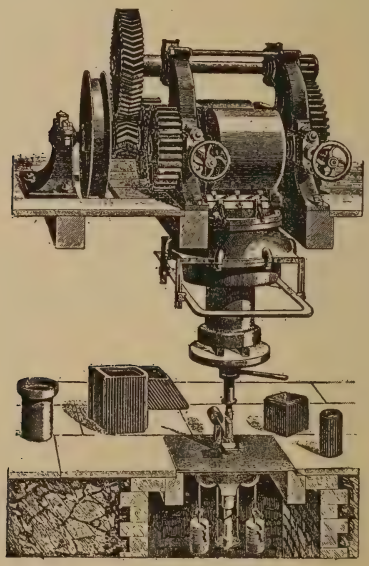


Fig. 294.—Expression rolls for pipes.

Engineering Company and others. Where more convenient, the opposite arrangement is adopted, the expression being from bottom upwards, as shown in Fig. 293. In that case, the socket-moulds are fixed on vertical rods, which are held immovable at their lower position while the socket is made, and are afterwards raised by a counterpoise. The working of these direct-acting machines is intermittent, because when the piston or propeller arrives at the end of its course it must be returned and the box must be filled afresh with the body. This takes a long time, because the body has to be pressed by mechanical power in such a way as to prevent, as much as possible, any air remaining in it. This air, in spite of the valves with which these machines are provided, will sometimes

form bubbles in the pipes and thus make them unusable. The continuous pipe-presses are, therefore, preferred whenever the nature of the clay permits them to be used.

Where the clay is easy to shape and especially for pipes with a diameter less than 28 in., expression rolls (Fig. 294) may be used to force the paste through the die and, instead of metal, the dies, as well as their core (beil), are covered with plaster. To avoid the production of air bubbles the men must be careful never to let the pressing-box become empty.

Small pipes may be made in groups of two or three, which can be made simultaneously, but the larger pipes must be made one at a time. The output of each machine varies with the rate at which the clay can be expressed without damage ; for pipes up to 10 in. diameter it is about fifty pipes per hour.

When the pipes are sufficiently stiff, they are placed on a horizontal cylinder or " fettler," sometimes covered with plaster, and are rotated rapidly to allow defective parts being touched up by hand, and for the spigot end of the pipes to be scratched so as to increase the adherence of the mortar or cement. The pipes are then placed in drying-sheds heated by steam or by waste heat from the kilns. In some works, the pipes are rolled on plain sheets of iron before they are completely dry, so as to get rid of the elliptical form that may easily occur when they are unequally dried.

Elbows, junctions (Fig. 291), etc., are made from straight pipes, which are cut off and joined together, or by moulding them in plaster moulds.

Burning.—The pipes are burned in rectangular or round down-draught kilns (usually the latter, Fig. 146) heated by coal. Many attempts have been made to use continuous kilns, but so far these have not proved satisfactory with salt glaze. In salting a kiln such as that shown in Fig. 295, the salt vapour is either carried forward into other chambers, where it comes in contact with goods at too low a temperature to be glazed, and so spoils them, or it is drawn off into the flues and blocks them by the formation of a thick viscous glaze on the arches or walls. Whilst it is possible to use such continuous kilns for salt glazing, their management is so difficult and stoppages for repairs are so frequent as to make their use for this purpose unsatisfactory. The pipes are placed upright one above another to a height of 6 to 8 ft. Care must be taken that the circulation of the kiln gases reaches the inside of the pipes in order that the salting may be done regularly on all sides. Small pipes may be put inside the larger ones, but, in spite of this facility, the weight of the goods placed in a given volume is small, and makes the cost of burning high as compared with bricks. The burning is effected in the same manner as for firebricks, until a temperature of about 1200° C. is reached, when, under normal conditions, the kiln is ready for salting. If the best results are to be obtained, the body should be partially vitrified at this temperature, though a sufficiently good result can be obtained on some porous bodies.

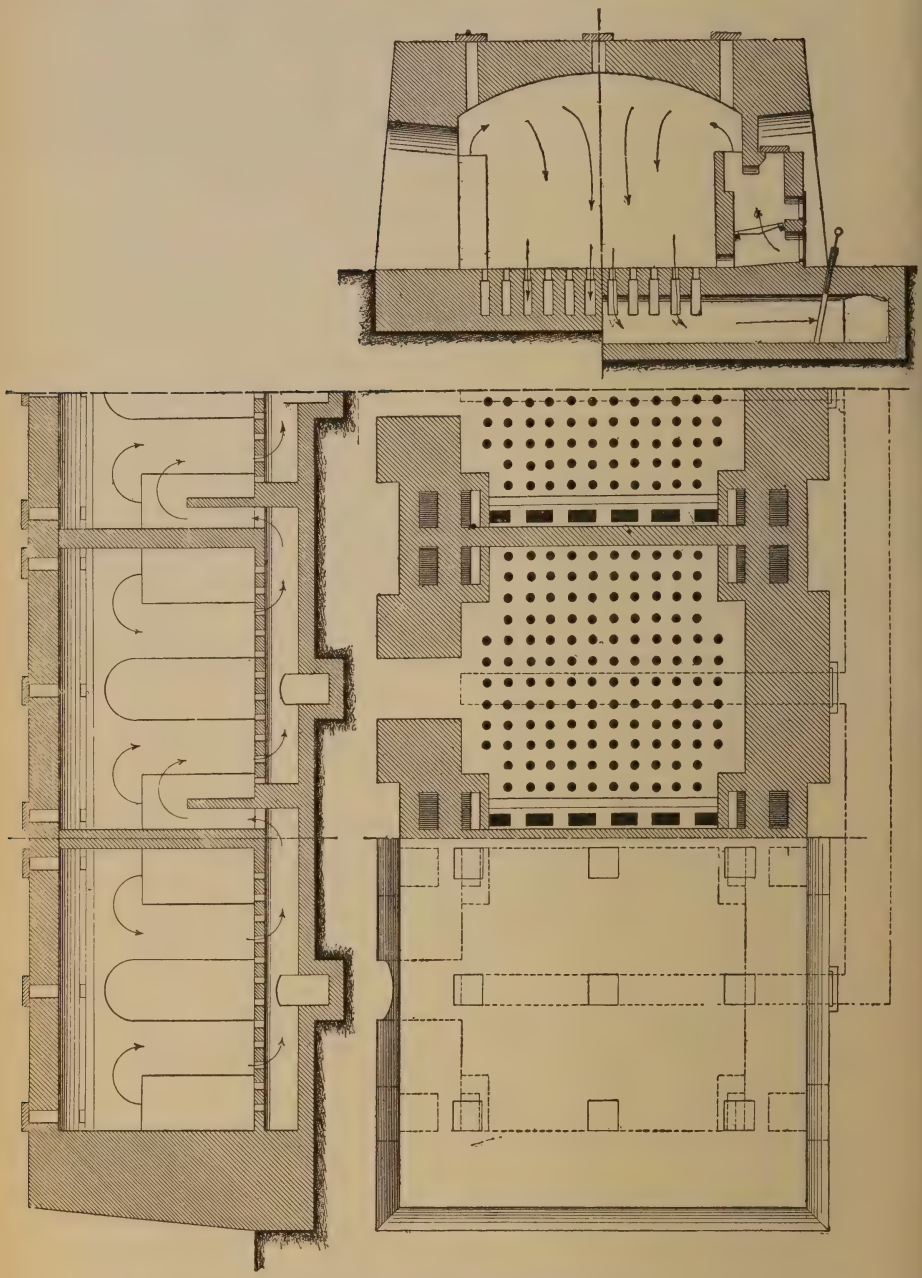


Fig. 295.—Semi-continuous kiln for pipes.

Salting.—The most characteristic operation of burning stoneware pipes is the salting, i.e. glazing the ware by throwing common salt (sodium chloride) into the kiln, at the time when the highest temperature has been reached. The salt volatilizes at a temperature slightly above 800° C., but only forms a glaze when (towards 1200° C.) it comes into contact with silica. The sodium oxidizes, forms soda, which combines with the silica of the body, and thus causes a superficial glaze. The chlorine, on its part, decomposes the steam furnished by the combustion and escapes in the form of fumes of hydrochloric acid. This decomposition is better, that is to say, the glaze is much thicker and more impermeable, the more silicious the body. Highly aluminous or decidedly basic wares cannot be covered with glaze in this way.

The salt is introduced into the kilns (i) through openings arranged in the top of the kiln, care being taken that it does not fall directly on to the goods ; or (ii) more usually by being thrown through the fire-holes on to the glowing fuel at the back of each fire-box. The volatilization and decomposition of the salt produces a decided and rapid lowering of the temperature by 200° to 300° C. The salting ought, therefore, to be done in two or three operations twenty to thirty minutes apart, and the temperature increased between them by refiring the kiln. The proportion of salt put in varies from $\frac{1}{2}$ lb. to $1\frac{1}{2}$ lb. per cubic foot capacity of the kiln.

While salting, the draught must be reduced to the minimum the intense heat will bear, so that the salt vapours may not be too quickly carried off into the chimney.

The final colour of the pipe naturally depends on the composition of the body and on the working of the fire during the time of burning which precedes the salting. It should not be reducing enough to cause a deposit of carbon on the goods, as this would afterwards prevent the contact of the silica and the salt vapour. If the proportion of salt is too great, the goods, after they have been some time in store, will show white deposits, which can be washed off.

The salt not only acts on the goods, but also on the walls of the kiln, and rapidly destroys them, if care has not been taken to employ sufficiently aluminous bricks in which little or no silica is found in a free state. Salting was practised for the first time in England about 1690 by the Brothers Elers.

Tests for Pipes.—The chief test for pipes is to ascertain their resistance to pressure (see p. 353). Pipes made of true stoneware resist a pressure of 5 to 15 atmospheres (70-220 lb. per square inch), or even more, without breaking. When the test is well conducted, that is to say, when the joints are well made and do not cause a supplementary strain on the material, the final breakage is produced along one of the edges of the pipe. Pipes made of a porous fireclay body are less resistant, and usually leak badly before breaking.

The tests are made either on a single pipe or on a series of to or three pipes connected together.

Sanitary Ware.

For some years past, the pottery ware used for sanitary and certain domestic purposes has been designated by this name. It is usually (but not always) distinguished from stoneware by a finer body and a more careful preparation ; sometimes the ware is covered with a salt glaze, but more usually with an opaque white glaze. Fig. 296 shows some of the most usual types.

The body is of two types : (i) porous and (ii) vitrified. Most of

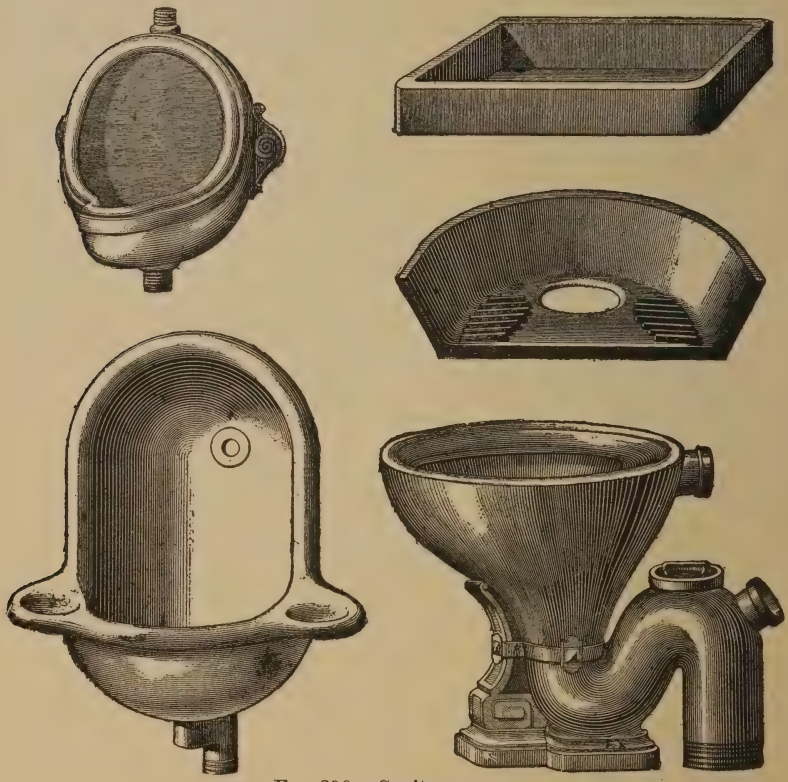


Fig. 296.—Sanitary ware.

the fixed sanitary ware used in England is made of fireclay, but most of that made in France and Germany is made of a finer body and is vitrified.

Each kind of body is prepared by grinding the materials to powder and then mixing them with sufficient water to form a paste. Occasionally, sanitary ware is made of fine earthenware, and the body is then made by filter-pressing a slip made by mixing the various materials and pugging the paste produced by the filter

press. Sanitary ware is usually shaped in plaster moulds, but for some articles wooden moulds are used.

The articles are dried on shelves or floors in artificially heated rooms, and are then taken to the kilns. Sometimes they are glazed in the green or unfired state, but more often they are fired, glazed and then re-fired. They may be burned in rectangular muffle kilns, or (if salt-glazed) they are burned in the same kind of kiln as salt-glazed pipes. Quite recently, tunnel kilns (p. 400) have been used very successfully for sanitary ware, and have effected a very great saving in fuel.

Unless salted, the glaze used is of the same composition as for felspathic faience, that is, an alkaline boracic plumbiferous one (p. 384), rendered opaque to hide the colour of the body by the addition of a little tin oxide or a leadless felspathic glaze composed of felspar, Cornish stone, whiting, and flint, which requires a fireclay body and a temperature of about 1300° C. These leadless glazes are the most popular for sanitary ware. If white ware is required, the body may be covered with a white slip or a little zinc oxide, or tin oxide may be added to the glaze. If desired, the glaze may be coloured by the addition of chromium, copper or cobalt oxide, or other colouring agents capable of withstanding a temperature of about 1300° C. For the more fusible boracic plumbiferous glazes, a wider range of colours is available. In some cases, the ware is gilded.

Sanitary ware is sometimes made of fine stoneware body, the body being then white ; transparent glazes are then used.

Sanitary ware was invented in England, and was for a long time manufactured exclusively in this country, but now several works in France and Germany produce articles which will bear comparison with the best English ware.

Stoneware for Food and Chemical Products.

The ware included under this heading is mostly "common" stoneware. The manufacture of pots intended to hold liquids was the first and, for a long time, the only use for stoneware, but towards the end of the eighteenth century it was used for making containers for chemicals, and for this purpose has reached a high point of perfection. The principal merit belongs to Messrs. Doulton & Co., who rendered an inestimable service to this industry. Fig. 297 represents some goods in common use in the chemical industries.

The body employed for the manufacture of these wares is usually a fairly pure vitrifiable clay, which does not need to be washed. It is carefully prepared and the articles are made principally on the wheel ; some pieces, however, on account of their shape, must be made in a mould.

For a long time these wares were burned in horizontal kilns with a single fireplace (Newcastle kilns), but it is better to use round down-draught kilns. Fig. 298 shows a kiln of this description,

which can also be used for burning pipes and other stoneware goods when the output is not sufficient to employ a continuous kiln. These kilns may be 23 to 26 ft. in diameter, the height not being more than $6\frac{1}{2}$ to 10 ft., because if the goods were placed to a greater height the lower ones would be crushed when they vitrify. The kiln-gases pass away through a large number of small openings in the floor, and thence to a central well or flue. The openings shown in the dome are used for salting, the salt being thrown on to the fireplaces, so as not to touch the ware.

This species of stoneware is generally rough or covered with a salt glaze when it is desirable to make it absolutely impermeable. The salt glaze may be given a deep brown colour by using the method indicated for making tiles black, immediately after the

Fig. 297.—Chemical stoneware.

addition of the salt. There is then formed a deposit of carbon which becomes incorporated in the glaze whilst it is still pasty. This method of colouring needs a considerable amount of skill.

The salt-glaze is sometimes replaced by a cheap glaze, applied (1) by dipping ; (2) with a brush ; or (3) by dusting on to the unburned body. This glaze must melt at the temperature which suffices to burn the body, and it cannot be plumbiferous. As the alkaline calcareous glazes are somewhat costly, they are sometimes partly replaced by blast furnace slag or by a mixture of cinders, lime, and sand.

Stoneware for preparing food or for chemical purposes is manufactured in England in large factories, while in France and Germany it is the speciality of a number of small potteries, which are grouped

together in the neighbourhood of the beds of vitrifiable clay ; the quality of these goods depends largely upon that of the clay used.

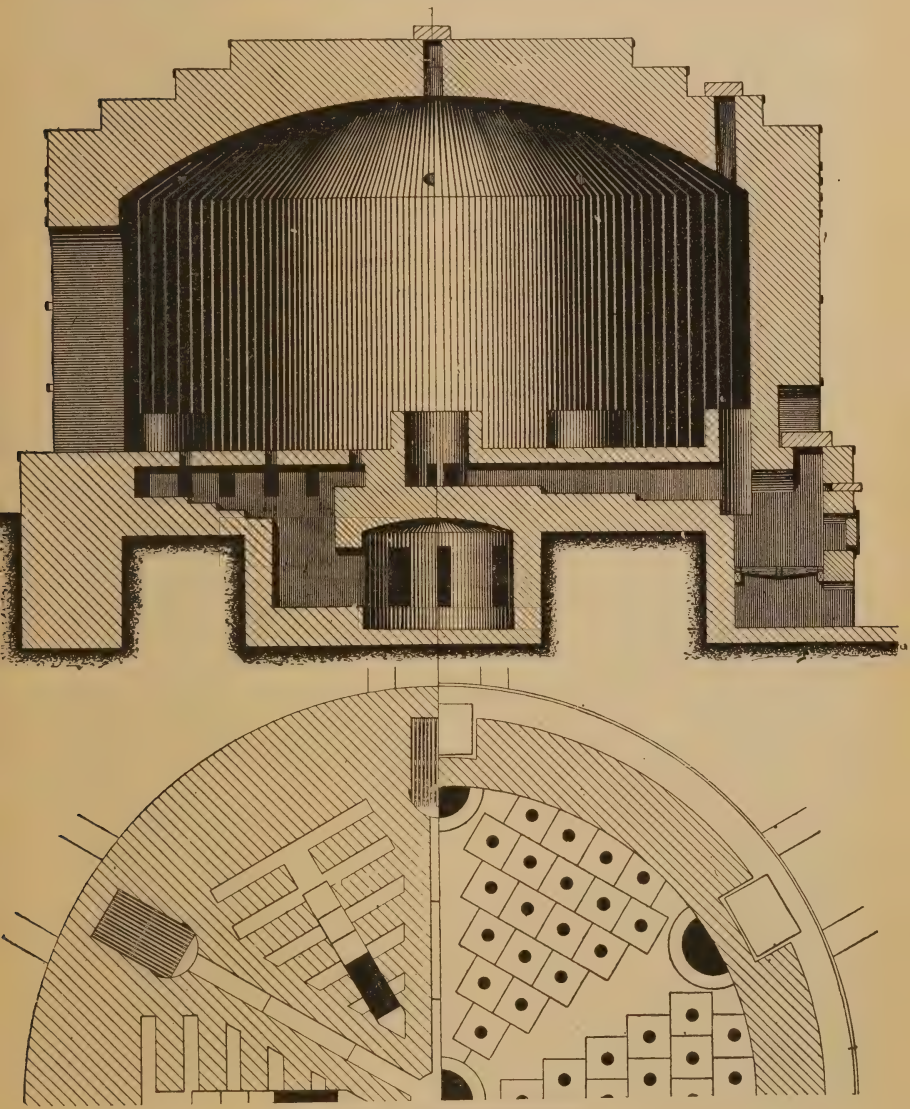


Fig. 298.—Kiln for stoneware.

Architectural Stoneware.

This term includes those varieties of stoneware which are used in the construction and decoration of buildings, for which purpose

the impermeability and hardness of stoneware give it a considerable advantage over terra-cotta. Unfortunately, this is largely counterbalanced by the difficulties in manufacturing it, and especially by the tendency of stoneware to get out of shape when being burned.

Architectural stoneware may have a dull surface or it may be covered with a salt- or other glaze. Transparent or coloured glazes allow very beautiful decorative effects to be obtained, which harmonize better with the architectural decoration than the hard tones of opaque enamels.

Vases, Statues and other Decorative Objects.

The Chinese used stoneware from very ancient times for the manufacture of vases and other ornamental objects, and this manufacture began in Europe in the fifteenth century, in the Duchy of Limburg. Since that time it has followed the fluctuations of fashion, disappearing completely, then reappearing again, without, however, at any time being of much importance. The first ware obtained by Böttger, which he termed *red porcelain*, belongs to this class. In the last few years the favour enjoyed by stoneware has caused a further development of this kind of ware. For these articles, which are rather expensive, bodies of different colours can be employed, and they must be saggared with great care to allow the use of vitrifiable clays without bad effects.

The great advantage of stoneware, as compared with porcelain or even calcareous or felspathic faience, is the plasticity of the body, which allows it to be modelled by hand or in moulds. As it lends itself to the same processes as modelling clay, it makes possible the creation of original works of art that possess, when burned, the same qualities of resistance and indestructibility as stone or bronze, without requiring any retouching, or the troublesome working inevitably associated with sculpture. Porcelain is not sufficiently plastic to be modelled so freely as stoneware, so that the shapes into which it can be made are more limited.

The close grain of the stoneware body, as well as its colour, also gives a more agreeable appearance to the object when modelled in stoneware than those made of terra-cotta.

Though decorative shaping should be the principal method of ornamenting stoneware, colour may also be used, and glazes blend very well with the more or less coloured background of the body, as they have not the hard appearance of other wares which are only partially glazed. All kinds of glazes and all methods of decoration can be employed ; though gilding, which is so suitable for porcelain, does not generally yield satisfactory results with stoneware.

Fine Stoneware.

In England, felspathic faience, fine stoneware, and bone china are so similar to one another, being manufactured by the same

methods, and burned at about the same temperature, that it is often difficult, and sometimes impossible, to distinguish them from each other by inspection only.

The raw materials of fine stoneware are the same as those used for felspathic faience, but the proportion of Cornish stone is increased and that of the flint diminished, thus :—

Blue clay	10	25	29	45	28
China clay	15	12½	14	15	—
Flint	20	12½	—	—	—
Cornish stone	55	50	57	40	72

The greater the amount of china clay the whiter the body ; with ball clay alone it is yellowish.

The chemical composition of white fine stoneware bodies is approximately :—

Silica	70 to 75 per cent.
Alumina	20 „ 25 „
Iron oxide	Traces.
Lime	0·5 to 1 „
Alkalies	3 „ 5 „

Heavy spar (barium sulphate) is sometimes added in large proportion (as much as 50 per cent), the amount of Cornish stone being then reduced.

The body is coloured by means already indicated : a ½ to 1 per cent of cobalt oxide gives blue, the same proportion of chromium oxide green, 7 to 8 per cent of a mixture of iron oxide and manganese oxide makes brown, etc. For basaltic black, the Cornish stone is replaced by a large proportion of red ochre and manganese oxide.

The body is prepared and moulded by the methods described for felspathic faience. It is also burned in the same way, and at the same temperature.

Fine stoneware is frequently dull. Sometimes the surface is vitrified by covering the inside of the saggars with a coating composed of sea salt, saltpetre, and white lead. The lead volatilizes, probably in the form of a chloride, and glazes the surface of the ware.

The glazes are usually alkaline, boracic, or plumbiferous, like those for felspathic faience ; sometimes the lead oxide and a part of the Cornish stone are replaced by barium sulphate.

CHAPTER XIV.

PORCELAIN.

Before the sixteenth century, the word "porcelain" was used to denote objects manufactured of mother-of-pearl from the shell called porcelain. After that time it was applied to Chinese ware.

Porcelain ware is impermeable and translucent, with a white or coloured body, but the latter is only for decorative purposes. The impermeability distinguishes porcelain from terra-cotta and faience, and its translucency makes it differ from stoneware.

In order to compare translucency precisely, it is necessary to specify the thickness of the body and the intensity of the light. When not too thick, pieces of light coloured stoneware and some felspathic faience rich in flux are somewhat translucent. On the other hand, all kinds of porcelain become opaque when the thickness of the body is sufficiently increased.

There is no precise rule for determining where opacity ceases and translucency begins—it is a question of appreciation.

The early Chinese porcelain—from which all others are derived—is of the *hard porcelain* type; many attempts to imitate it without sufficient knowledge of its composition resulted in the production of the *soft porcelains*. The two adjectives "hard" and "soft," relate first to the resistance of the ware to heat, and afterwards to the mechanical hardness of the glaze.

Hard porcelain has a silicious body made of china clay and alkaline or partly calcareous fluxes. It is usually covered with a glaze, the vitrification of which takes place at the same time as the burning of the body, at a temperature of 1300° to 1400° C. The glaze is so hard when fired that it cannot be scratched with steel. Hard porcelain forms a well-defined group of ware, and is easily distinguished from other wares; the six following varieties may be distinguished: (*a*) *Porcelain for table-ware and for decoration;* (*b*) *refractory porcelain* intended to be submitted to heat; (*c*) *Porcelain for electrical insulators;* (*d*) *porcelain for mechanical purposes;* (*e*) *architectural porcelain;* and (*f*) *dull porcelain* (*biscuit porcelain*).

Soft or *tender porcelain*, on the contrary, is very different from hard porcelain, with which it has scarcely anything in common, being made of different materials, burned at a lower temperature, and having a softer glaze.

Hard Porcelain.

Porcelain for Table-ware and Ornamental Ware.

Hard porcelain is chiefly made in France, Saxony, Bavaria, Thuringia, Silesia, Bohemia, Belgium, Denmark, Russia (Finland and Poland), Italy (Tuscany), the United States (New Jersey and Ohio), China (Kiang-Si), and in Japan. Hard porcelain is not made extensively in England.

It is generally agreed that 8 cwt. of various raw materials must be used for manufacturing 1 cwt. of porcelain. The chief of these are fuel, fireclay, china clay, felspar or Cornish stone, quartz, plaster (for the moulds), etc. As all these products are not found in one single locality, it is necessary, in choosing the site for a new factory, to take into account the different expenses of transport, and especially that of the fuel and fireclay. It is equally necessary to think about labour, because great skill is required in moulding, saggaring, decoration, and firing.

The body for hard porcelain is usually a mixture of china clay, silica, and alkaline fluxes, but sometimes part of the alkalies is replaced by lime. In very rare cases, magnesite or talc is partially substituted for the china clay.

Hard porcelain body should—

1. Have sufficient plasticity to be suitable for moulding.
2. Be burned at a sufficiently high temperature to allow the employment of a very hard glaze.
3. Have as great a translucency as possible.
4. Be of a slightly bluish-white colour.

The bodies of hard porcelains are difficult to shape because they are deficient in plasticity. A highly plastic clay, which serves as a basis for all the bodies previously described, cannot be used, as it would produce bodies which are too fusible or opaque, and would not be of the required whiteness. Kaolin or china clay is more refractory and makes more translucent and whiter bodies, but even these clays vary greatly in composition and properties. Their value must be decided on a "rational analysis" (treatment with sulphuric acid).[1] The alkalies dissolved by this treatment may be ascribed to mica, by regarding it as having the composition of muscovite, $6SiO_2$, $3Al_2O_3$, K_2O, $2H_2O$, and the insoluble alkalies, as orthoclase felspar, $6SiO_2$, $4Al_2O_3$, K_2O, any soda being reckoned as an equivalent of potash. Thus, the proportions of the mixture of alumino-silicic acid ("true clay"), quartz, felspar, and mica which make up the china clay are obtained with a degree of accuracy sufficient for most purposes.

[1] There are many irregularities observed when this method of analysis is used. On the whole, a very full ultimate analysis, combined with a careful microscopical examination, is superior.

It is also necessary to make a practical experiment in order to ascertain the plasticity of the body. The dimensions and probably the shape of the grains of clay are, in fact, more variable in china clay than in the plastic clays; the higher its plasticity, as in the Cornish china clays, the nearer it resembles the corresponding clays (kaolins) used in China and Japan.[1]

The non-plastic materials added are quartz, quartzose sand, or biscuit porcelain; the fluxes are felspar, Cornish stone, whiting, or chalk. When a single china clay (especially if it is a lean one) cannot give the needful plasticity or other desired properties, two or even three kaolins or china clays are mixed together.

The following are typical analyses, the first eight being burned porcelains and the last eleven raw bodies :—

		Silica.	Alumina.	Iron Oxide.	Lime.	Magnesia.	Potash.	Soda.	Water.	Carbonic Acid.
Burned Procelain.	Meissen	58·5	35·1	0·8	0·3	0·6	5·0	—	—	—
	„	60·0	35·5	—	0·6	—	2·3	1·6	—	—
	Vienna	59·6	34·2	0·8	1·7	1·4	2·0	—	—	—
	Nymphenburg	72·8	18·4	2·5	3·3	0·3	0·6	1·8	—	—
	Berlin	64·3	29·0	0·6	0·3	0·5	3·6	—	—	—
	China	69·0	23·6	1·2	0·3	—	3·3	2·9	—	—
	„	70·0	22·2	1·3	0·8	—	3·6	2·7	—	—
	„	73·3	19·3	2·0	0·6	—	2·5	2·3	—	—
Raw Bodies.	Sèvres body for tableware	52·94	28·91	0·48	3·99	0·17	1·70	0·68	9·12	2·48
	Limoges (L. Pouyat) superfine body	64·28	23·49	0·87	1·77	tr.	1·11	3·07	5·48	0·69
	Limoges (L. Sazerat) ordinary body	60·42	26·47	0·52	1·37	tr.	2·75	1·60	7·19	—
	Limoges (Geurin et Cie) superfine body	65·61	23·07	0·65	0·80	tr.	2·94	2·72	4·50	—
	Limoges (Geurin et Cie) ordinary body	66·00	22·59	0·36	1·68	—	2·71	1·80	5·59	—
	Vierzon heavy porcelain	63·48	25·00	0·51	1·06	—	2·26	1·19	6·76	—
	Hal (Belgium) heavy porcelain	63·95	25·59	0·69	tr.	0·54	2·07	0·98	6·62	—
	Berlin table porcelain	63·07	24·67	0·59	—	0·40	4·25	—	7·00	—
	Japan	74·53	16·09	1·03	0·06	0·25	4·37	1·19	2·83	—
	„	71·31	19·74	0·73	0·17	—	4·04	0·10	4·01	—
	„	71·60	18·71	1·19	tr.	—	4·16	0·18	4·68	—

By comparing the foregoing figures, Seger recognized four types of porcelain : (1) Sèvres porcelain ; (2) heavy French porcelain, Hal porcelain, and Berlin porcelain ; (3) French porcelain of superfine quality ; and (4) Chinese and Japanese porcelains.

[1] It has even been suggested that the ancient Chinese and Japanese porcelains bear a closer resemblance to stoneware than to much modern porcelain !

The respective compositions of these four types group themselves more clearly if Seger's average figures are taken for the burned bodies :—

	Silica.	Alumina.	Iron Oxide.	Lime.	Potash.	Soda.
Type 1	59·6	32·6	0·6	4·5	2·0	0·7
„ 2	67·8	26·7	0·7	0·8	2·9	1·1
„ 3	69·1	24·0	0·7	1·6	2·3	2·3
„ 4	75·5	19·0	1·0	—	4·3	0·6

The comparison may be still further facilitated by representing the composition by the symbol $m\mathrm{RO}$, $\mathrm{R_2O_3}$, $n\mathrm{SiO_2}$, in which $m\mathrm{RO}$ represents the fluxes (lime, magnesia, potash, and soda), $\mathrm{R_2O_3}$ the alumina and iron oxide taken together, and $n\mathrm{SiO_2}$ the proportion of silica.

Under these conditions, these typical porcelains correspond to the formulæ :—

Typical Formulæ for Porcelain.

Type 1	0·30 to 0·35 RO, $\mathrm{R_2O_3}$, 2·8 to 3·5 $\mathrm{SiO_2}$
„ 2	0·20 „ 0·30 RO, $\mathrm{R_2O_3}$, 4·2 „ 4·8 $\mathrm{SiO_2}$
„ 3	0·40 „ 0·45 RO, $\mathrm{R_2O_3}$, 4·8 „ 5·3 $\mathrm{SiO_2}$
„ 4*a*	0·40 „ 0·45 RO, $\mathrm{R_2O_3}$, 5·5 „ 6·0 $\mathrm{SiO_2}$
„ 4*b*	0·30 „ 0·40 RO, $\mathrm{R_2O_3}$, 6·2 „ 7·4 $\mathrm{SiO_2}$

At the high temperature at which porcelain is burned, the silica becomes a fusible element, hence in the foregoing table the bodies are in the order of their fusibility. According to Vogt, the Sèvres body, which is the most refractory, is burned at Seger cone 15 and the Chinese bodies at cone 12.

The following table, based on rational analysis and on the calculations described on page 437, shows the minerals presumably present in each type of porcelain :—

	Calcium Carbonate (Chalk).	Soluble in Sulphuric Acid.		Insoluble in Sulphuric Acid.	
		Alumino-Silicic Acid (Clay).	Mica.	Quartz.	Felspar.
Type 1	6·47	59·80	6·57	12·05	15·11
„ 2	—	48·89	6·28	24·34	20·49
„ 3	—	40·99	4·13	23·87	31·01
„ 4	—	33·13	9·56	42·60	14·71

Vogt has shown, by experiment, that impalpable mica possesses a plasticity analogous to that of the true clay, and the high proportion of this material often found in Oriental porcelain bodies explains in some measure their remarkable plasticity ; it must also be admitted that the alumino-silicic acid in the kaolins from China and Japan is more plastic than that in the European ones, including Cornish china clay. Attempts have been made to produce European bodies as plastic as the Oriental ones by adding plastic clay, but this result seriously lessens the whiteness and translucency of the ware.

The raw materials used in France are principally the felspathic clay from St. Yrieix, with the addition of a quartzose stone found in the same beds, and a little grog obtained by powdering biscuit porcelain. Sometimes a little marble or chalk is added. In Germany and Austria, where the china clays contain very little felspar, a special mixture of china clay, felspar, and quartz must be made.

The body is always prepared in a slip state. The clay is first sorted and carefully washed, unless bought ready for use as is now customary ; the quartz and felspathic rocks are also sorted and then ground to powder. As stated on page 100, the body may be prepared by two methods. In the first, the measuring is done when the materials are dry, and they are afterwards mixed with water and ground, while in the second, the measuring takes place when the materials are in a liquid state, as they have been separately mixed with water before or after grinding. The first method is used at Limoges ; the second in England, Germany, and Austria. Whatever the method of grinding and measuring, the liquid body (slip) is afterwards sifted, submitted to the action of electric magnets to remove any iron particles, and is then made into a firm cake in a filter press. These moist cakes are placed in cellars, where they are kept for some time before being used. In some cases, the materials used for making the bodies are prepared in special factories.

Previous to moulding, the cake of body is passed through a pug-mill (water being added to it if necessary), to get rid of any air-bubbles it may contain (see p. 94).

The glazes employed for hard porcelain are calcareous and alkali alumino-silicates. According as the calcareous bases or alkalies preponderate, the glaze is termed calcareous or felspathic ; the latter should not be termed alkaline, though frequently so-called.

The following table shows the chemical composition of some of the glazes. The first analysis is by Vogt, the other six are by Seger :—

	Silica.	Alumina.	Oxide of Iron.	Lime.	Magnesia.	Potash.	Soda.	Loss in the Kiln, etc.
Pegmatite used at Sèvres	70·64	16·87	0·73	1·31	0·20	4·22	4·97	0·34
„ „ Limoges	76·11	14·61	0·66	1·44	0·42	2·99	3·03	1·23
„ „ „	73·99	14·80	0·37	1·09	0·36	4·31	3·49	0·65
Glaze used at Berlin .	73·24	13·97	0·31	2·57	0·51	4·81	1·71	3·83
Japanese glaze . .	61·97	12·92	0·39	9·59	Tr.	4·17	1·12	10·21 (1)
„ „ . .	64·96	12·74	0·80	8·78	Tr.	1·95	2·30	9·35 (2)
Chinese sea-green glaze .	64·80	14·33	1·39	10·09	1·55	5·61	0·81	1·39 (3)

(1) 0·30 of phosphoric acid is included.
(2) 0·16 of phosphoric acid is included.
(3) Titanic acid.

The first four glazes are felspathic and the last three calcareous ones ; they may be represented by the following formulæ, in which RO indicates the fluxes, R_2O_3 the alumina and iron oxide, and SiO_2 the silica :—

Pegmatite used at Sèvres . . 1·0 RO, 1·07 R_2O_3, 7·45 SiO_2.
„ „ Limoges . . 1·0 RO, 1·00 R_2O_3, 8·91 SiO_2.
„ „ „ . 1·0 RO, 1·24 R_2O_3, 10·84 SiO_2.
Glaze used at Berlin . . . 1·0 RO, 1·12 R_2O_3, 9·58 SiO_2.
„ Japanese . . . . 1·0 RO, 0·55 R_2O_3, 4·42 SiO_2.
„ „ . . . . 1·0 RO, 0·59 R_2O_3, 5·04 SiO_2.
„ Chinese . . . . 1·0 RO, 0·52 R_2O_3, 3·82 SiO_2.

The relative proportion of silica and alumina varies little, but there is double the amount of fluxes in the oriental glazes ; this accounts for their greater fusibility.

In France, pegmatite from St. Yrieix is almost exclusively used as a glaze. It closely resembles a mixture of felspar, quartz, and china clay. Its fusibility may be regulated by the addition of quartz.

In Germany and Austria, the glaze is composed of a mixture of felspar, quartz, and kaolin. In those countries for a long time, and even now to a great extent, calcareous glazes were used, the lime being introduced in the form of marble, chalk, or whiting, or as a burnt calcium sulphate (over-burned plaster of Paris). The following are the compositions of some of these porcelains (Prosser) :—

Quartz	34·5	32·0	27·0	50·0	44·0
China clay	9·5	7·0	8·0	37·5	30·0
Felspar	32·5	37·0	32·0	—	—
Calcium carbonate	12·0	11·0	16·5	12·5	—
Calcium sulphate	—	—	—	—	13·5
Grog (biscuit porcelain) . . .	11·5	13·0	16·5	—	12·5

In China and Japan, the glaze appears to be made of a stone similar to pegmatite (Cornish stone), finely powdered, and diluted in milk of lime.

The calcareous glazes are usually more transparent and penetrate into the body better than the felspathic ones, which are more milky and need to be applied in a thicker layer. But, as the latter give a more velvety and agreeable appearance to the porcelain, they are generally preferred. The burning of the body and the glaze is simultaneous, so that there must be a complete agreement between the temperature needed for vitrifying the body and that for burning the glaze. The foregoing analyses show the ordinary limits within which the respective proportions of alumina, silica, and fluxes may be varied to attain this end.

The moulding of porcelain presents much greater difficulties than that of any other ware, as the body, which is nearly always a very "lean" or "short" one, lends itself very badly to all methods of moulding based on the use of a plastic material. Later, in the firing the ware softens and consequently tends to collapse under its own weight, so that it is necessary to give it a variable thickness, strengthening the parts which act as supports when the ware is in the kiln and diminishing the thickness of the other parts. Lastly, on account of the considerable shrinkage which takes place during vitrification, porcelain tends to lose its shape if the body is not of an absolutely uniform density in all its parts. It is so sensitive that a touch of the hand may compress the body sufficiently to make the ware warp. Nevertheless, the methods already mentioned in Chapter V may be used for moulding porcelain, if the following precautions are taken :—

Throwing can only produce a rough form, because the low plasticity of the body necessitates the walls being of an undesirable thickness. The ware must, therefore, be finished off by *turning* the body on a lathe when it is partially dried, or even when quite dry. As the quantity of body to be removed during this operation is large, many scraps are formed and are used again. A thick dust is also formed which is inconvenient and injurious to the health of the workman, who must wear a mask and be provided with a good mechanical ventilator.

Expression is made difficult by the low plasticity of the body, and so is seldom used, except for special pieces.

Moulding by hand in plaster moulds needs special care, so as to press the body equally into all parts of the mould and in making the joints. The bats of body must themselves have been made with equal care and they should be cut out in such a way as to correspond exactly when put together with the mould. They should be made on a cloth or piece of damp leather (p. 126), which is used to lift them and convey them to the mould. When they are in a suitable position, the cloth is taken away, and the body is pressed lightly by means of a sponge, any necessary joints being made at the same time. The body is dried and trimmed to remove the ridges, etc. This operation also produces a large amount of dust.

Moulding on a jolley is the most usual method of working porcelain, as it is not only the most convenient, but most of the porcelain

goods are of a shape which lends itself to it. It is always preceded by throwing a bat for flat pieces ; covers for hollow ware are made on the wheel, giving them a very regular form and smoothing the surfaces, as this is an indispensable condition. The bat, or shape, having been applied to the mould, it is pressed down by means of a sponge, beginning at the centre. For narrow vases, into which the hand cannot be placed, the sponge is fixed on a stick.

The piece having thus taken its definite shape from one side of the mould, the other face can sometimes be simply moulded by the sponge, but it is usually necessary to have a second special moulding. In Britain, Germany, and Austria this is chiefly done with templets, as described on pages 133 and 393. In France, the stiffened body is turned on vertical or horizontal lathes, according to the shape of the pieces, the body being still in the mould, though some pieces can wait until they are sufficiently dry to be put direct on to the wheel. Each method has its own advantages and disadvantages ; the second one makes pieces of better quality, but needs very skilful workmen.

For flat pieces, the following method of *jiggering* may also be used. It was invented by Faure at Limoges, and allows all open hollow goods to be moulded on the jigger with templets. There are four operations :—

(1) Making the bat.
(2) Putting the bat in the centre of the plaster mould.
(3) Making the outside shape with a templet.
(4) Turning the edges.

As already stated, the bats are moulded on a skin stretched over a copper ring, and fitted on to the head of the machine (see p. 130). In the centre is placed a lump of clay of a definite size, and the machine is set in motion ; the templet descends and ascends automatically. The bat, when finished, is taken up with the skin and the disc, and the whole is placed under the circular plate of the shaping machine. This plate is lowered in such a way as to place the bat on the plaster mould ; it is then taken off by putting a wooden knife between it and the leather. The plate is raised, the wheel started by pressing on the pedal, and the bat is pressed on to the mould with a sponge, working from the centre to the circumference, to prevent any air remaining between the mould and the bat.

The mould is then placed on the head of the jigger (Fig. 299), and the latter is started by depressing the pedal at the left. A tool first starts from the centre, and going outwards forms the bottom, then it is raised to shape the foot, and descends again along the edge. A second tool, which is really a templet, is then lowered and gives the final shape. This machine makes about sixty plates an hour. It may be used to obtain all round forms (plates, dishes, and shallow bowls) by regulating the course of the templet by means of an upper screw, and by using templets with different profiles. A more modern machine for the same purpose is shown in Fig. 300. The ware thus

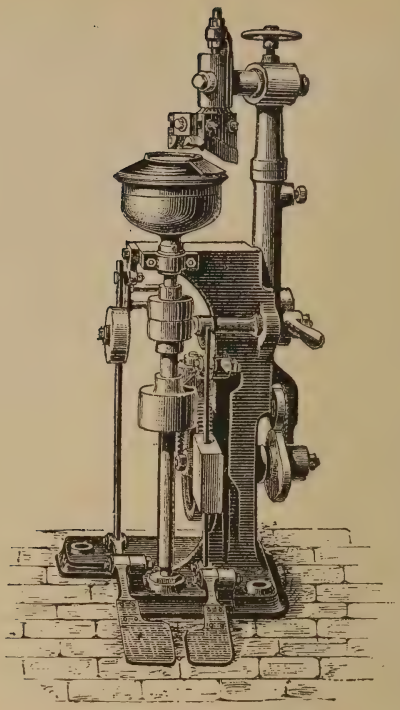


FIG. 299.—Jigger for plates.

FIG. 300.—Flat-ware jigger.

cut by the templet is finally placed on a third wheel, where the edges are rounded off and made thinner.

Faure also constructed a machine, shown in Fig. 301, for making oval dishes. The bat, having been made as described, is shaped by means of a plate balanced and guided by two stems; then, this

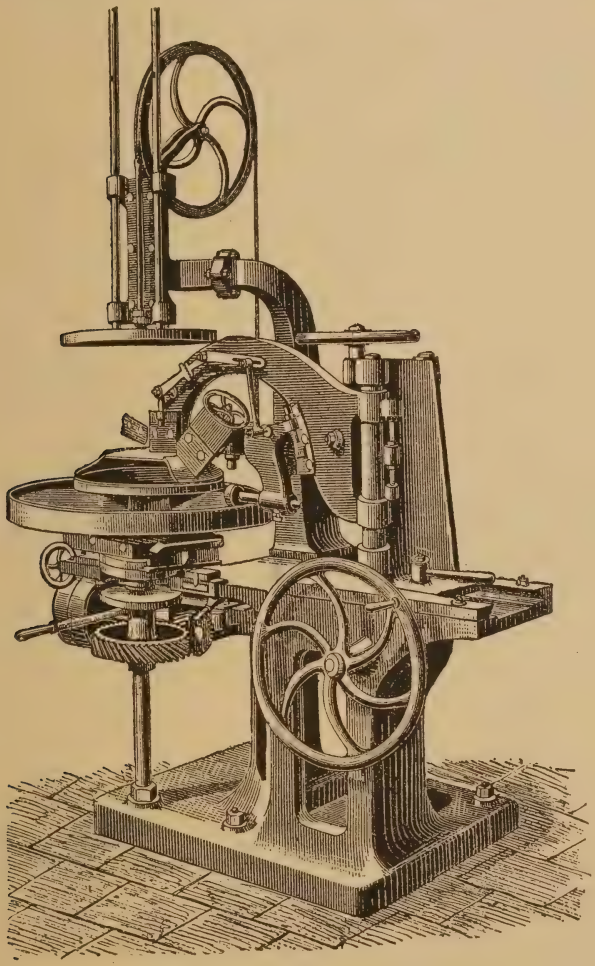


Fig. 301.—Jigger for oval ware.

plate having been raised again, the frame carrying the templets is made to revolve; these are put in contact with the bat, and the wheel, which is furnished with an arrangement to give it an oval motion, is started. The templets are arranged as in the preceding

machine, but with this difference, that the part of the templet which forms the edges is moved with a slightly oscillating motion, made necessary by the greater width of the edges on account of the large axis of the dish. This oscillating motion is transmitted to the templet by a series of levers worked by a roller, under which turns the rim of a large plate placed under the mould. This rim has various heights; being raised more in the parts which correspond to the long axis, so that it raises or lowers the roller progressively to suit the slope of the templet.

Moulding in a press is only used for small objects. The body is first thrown or shaped by hand, and is then compressed between two plaster moulds. The stiffened body may be re-pressed if desired.

Moulding by casting is very suitable for lean bodies such as porcelain, and it is largely used for making objects with thin sides which it would be difficult to obtain with any other processes. This method is described on page 141. The thickness of the body can be varied by diminishing the absorption of the plaster in certain parts, or by adding a little body by hand while the piece is still in the mould.

The *finishing* of porcelain is more important than in any other ware. The different operations are described on page 142.

The drying, burning, and application of the glaze to thin and porous pieces, such as porcelain bodies, does not present any special difficulty. They are usually dried in the workshops, which are provided with heating apparatus, though artificially-heated drying-sheds similar to those employed in other works may be used, especially for drying the moulds.

In order to facilitate the application of the glaze, the bodies are first fired at a temperature of about 800° C., using the waste heat from the glost kilns. The body must not be heated to too high a temperature, which would diminish its porosity too much, and make it incapable of absorbing sufficient glaze. In the first firing, the ware is packed in saggars, the pieces being piled on one another until the saggars are filled.

The biscuit ware so produced is carefully brushed and then covered with glaze. This latter is in the form of a slip, of a consistency which may be varied according to the thickness of the layer desired. It is nearly always applied by dipping, only very fragile pieces being sprayed or dusted. The layer of glaze in contact with the porous body dries rapidly and after a short time the goods may be taken to the glost kiln.

Burning.—Round kilns with up-draught and heated by wood were, for a long time, exclusively used for burning porcelain. The wood was later replaced by coal, and down-draught kilns substituted. Fig. 147 shows the arrangement generally used at the present time. The dimensions of these kilns vary greatly, but in order to obtain a suitable distribution of the heat it is wise not to have the interior diameter more than 16 to 20 ft. The height of the burning space

should be a little less than the diameter. The number of fireplaces varies from three to eight. Fig. 148 represents a kiln of the same kind, but in this the second chamber is below the fireplace, thus necessitating an independent chimney. This type of kiln has several theoretical advantages over the preceding one.

The slow firing is relatively short and easily managed on account of the very small amount of moisture in the ware. The same applies to the hard firing, up to about 1200° C. From that time the atmosphere of the kilns must be reducing, in order to avoid a yellow colour (due to the peroxide of iron in the body), which is replaced in a reducing atmosphere by the slightly bluish colour of the protoxide. This reducing action would not be difficult if there were no risk of the hydrocarbons diffusing through the walls of the saggars (see p. 239) and, by decomposing, leaving a deposit of carbon on the ware which, during vitrification, would be incorporated in the glaze and would give the ware a red smoked colour. When, in the course of the burning, it is noticed that the atmosphere in the kiln is clouded by the presence of these hydrocarbons (which have a tendency to accumulate under the dome at the place where the circulation of the gases is least active) the reducing action must be stopped for a time, and the fires made oxidizing to burn up the deposited carbon. The firemen call this " washing " the kiln.

It is not easy to find the true mean between an oxidizing atmosphere, a neutral one, and one which is excessively reducing, especially where the fireplaces are difficult to regulate. It is also very necessary that the atmosphere of the kilns should be as uniform as possible, *i.e.* there should not be parts where it is extra-reducing. This condition can only be obtained by a rational arrangement of the fireplaces. It is equally indispensable that the gases in the kiln should be under slight pressure, to prevent air leaking in through cracks in the walls. For this reason, the openings for letting off the gases are made of rather narrow section, and the flues for the smoke are made wider.

The dimensions of the grates depend upon the volume of the combustion chamber or burning space, and on the fuel, so that it is impossible to give precise directions in relation to them. As a general rule, the fireboxes used are too small.

The duration of the burning varies from eighteen to thirty-six or even forty hours. Naturally, it pays to hasten it as much as possible, within the limits necessitated by the sensitiveness of fireproof materials to a rapid rise in temperature.

The first part of the cooling should be in a reducing atmosphere, until the glaze is solidified. After that, the atmosphere may be neutral, and below 800° C. it may be oxidizing.

The thermal balance sheet of this class of kiln is roughly as follows :—

Heat produced by combustion	100	Heat theoretically needed	10
		Heat used in the furnace	6
		Heat lost in heating saggars	38
		Heat lost by the heating of the walls	12
		Heat lost by radiation	10
		Heat lost through the chimney	20
		Heat lost by the reducing atmosphere	1
		Heat lost by incomplete combustion	3
	100		100

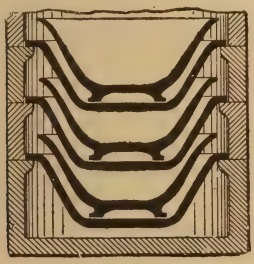
At the chief porcelain manufactory in Berlin, a continuous kiln, constructed on the Mendheim system (Fig. 287), has been used for a long time. As the general working of continuous kilns is always decidedly oxidizing, it has not been possible in this kiln to get the powerful reducing atmosphere necessary for burning porcelain, except by various expedients, the principal one consisting of rather rapidly cooling the compartment in which the burning has just been finished, so as to solidify the glaze and thus protect the body against the oxidizing action of the air. The results attained by this kiln are, for this reason, only partially satisfactory for porcelain, and for this class of ware it seems unlikely that, in the present state of the porcelain industry and of the knowledge of industrial physics, burning in a continuous kiln can be used to any great advantage. The reader interested in this subject is referred to the argument used in burning earthenware (p. 400), but the economy would reach scarcely 10 or 15 per cent, and would be counterbalanced by the annoyances of a much longer burning and important modifications in existing factories. It would be better to copy the Chinese and use semi-continuous kilns. The author believes that more progress may be made by better construction of the present single kilns, and by using gas instead of solid fuel, or possibly by modifying some form of tunnel kiln.

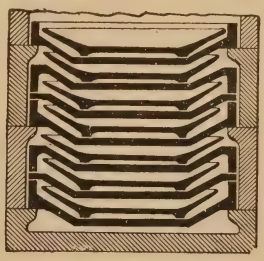
Saggaring glazed ware is a source of great trouble in burning porcelain, as nearly all the pieces have to be supported separately; the supports in the saggars increases the dead weight as compared with the useful weight of material in the kiln, and the high temperature at which they are burned necessitates the use of saggars and supports made of expensive fireproof materials, the wear and tear of which is very considerable. As the dead weight is usually four times the weight of the ware, and the supports must be set so that the ware will not get out of place, it is easy to understand the importance of good saggars in the manufacture of porcelain.

The piles of saggars are arranged in the kilns in the same way as when burning earthenware, but the saggaring is entirely different. In some respects the best arrangement would be to have only one piece of ware in each saggar (Fig. 302), but that is often impracticable. With flat objects such as plates, three pieces may be placed in a saggar, by using the arrangement shown in Fig. 303.

When the pieces of ware rest on their feet, the lower surface of the feet should be unglazed. They can be prevented from sticking by powdering the bottom of the saggar with a little quartzose sand or by smearing the parts in contact with a little fireclay. In special cases it may be better to place the objects upside down in the saggar, leaving their upper edges without glaze ; they should afterwards be gilded. Larger pieces, or those in which the foot is too small, should be supported to prevent them getting out of shape or sinking down. All parts in contact with the supports must remain unglazed, and be decorated later. In some cases, the ware must be held up from the inside by means of pieces or supports of unburned body, which can, naturally, be used only once. For goods of very large dimensions, it is necessary to use a muffle-kiln, or a " chamber " built of slabs on several piles of saggars.

Such is a very brief summary of the principles of saggaring porcelain. The application of them needs much practice, much care, and the knowledge of many special expedients.





Figs. 302 and 303.—Methods of saggaring.

Dressing.—Burned ware, the foot of which is slightly out of shape, may be trued up on rapidly rotating horizontal plates of cast-iron, covered with sand and water, similar to those used for polishing stove-tiles. Polishers are also used for removing small grains of sand or pieces of the saggars which fall on to the ware while it is being burned and become incorporated in the glaze. These polishers, like those used in glass-making, are of hard stone-ware, or of a mixture of porcelain body and quartz which has been heated thoroughly.

The decoration of hard porcelain presents special difficulties. The slight plasticity of the body makes *decorative moulding* very difficult. The Chinese discovered various expedients in moulding, but the body they used is more plastic than ours, and labour is cheaper.

Decorating with colour presents difficulties of another kind, as on account of the high temperature at which the burning must take place only a small number of colouring materials can be employed.

The body may be coloured by the following materials :—

Blue.—Cobalt oxide, the shade being modified by a mixture of

chrome oxide or uranium oxide. It is desirable to frit the cobalt oxide with zinc oxide before mixing it with the body.

Grey.—Iridium oxide and platinum. The tone can be improved by adding cobalt oxide.

Yellow.—Uranium oxide.

Brown.—Mixtures, in various proportions, of iron oxide, iron chromate and manganese oxide.

Rose.—A mixture of alumina and potassium chromate is first heated in the hard fire with an oxidizing atmosphere, and afterwards added to the body.

The introduction of these colouring materials into the body has the effect of varying its fusibility, and it is necessary to modify its composition by the addition of china clay or felspar.

Under-glaze colour is little used on account of the small number of colours which can be employed. Only one, cobalt oxide, is much used, though the oxides of uranium, chrome and iridium, a mixture of chromate of iron and manganese oxide, etc., might also be employed. These oxides are generally mixed with the body, heated in a hard fire, and then applied to the biscuit. It is then necessary to fix the colour by burning the body before the glaze is applied. Generally, the colours thus obtained are rather dull, as no glaze is completely transparent.

Over-glaze colouring may be obtained on *hard-fired ware* [1] by putting the colour on the vitrified glaze and heating it a second time in saggars, with an ordinary burning. The colours thus used have a flux (ordinary glaze modified by the addition of some alkaline-earthy bases) added to them in order to cause them to adhere to the ware.

Theoretically, in order to prevent the action of the flux on the colour, it is necessary to combine a protoxide with a sesquioxide. The colour may then be represented by the formula RO, R_2O_3, in which RO represents a colouring protoxide or an alkaline-earthy base, and R_2O_3 alumina or a colouring sesquioxide. The most popular combinations of this kind are :—

Aluminate of cobalt	CoO, Al_2O_3
Aluminate of zinc and cobalt . . .	$\left\{\begin{matrix}ZnO\\CoO\end{matrix}\right\} Al_2O_3$
Aluminate of chrome	CrO, Al_2O_3.
Chromate of cobalt	CoO, Cr_2O_3.
Chromate of iron	FeO, Cr_2O_3.

These compounds are first heated in the hard fire and are then ground and mixed with a flux. Very stable oxides, such as those of titanium, uranium, platinum, iridium, may be used direct.

The colours thus obtained are black, blue of different shades, emerald green, yellow, various browns, rose, brick red. This method of decoration in the hard firing, though lacking the brilliancy of trans-

[1] It is difficult to apply the colour to the unburned glaze and this process is seldom employed.

parent faience enamels, is of a much richer and more brilliant colour than that obtainable with muffle-firing.

Over-glaze colouring with muffle firing is, however, much more used. It is based on the employment of vitrifiable colours such as those mentioned on page 270, the burning being done in a muffle at the temperature corresponding to the test for gold. The vitrifiable colours are usually manufactured in special works, and can easily be procured in commerce, though some factories prepare them themselves. The colours are mixed with fluxes ; the following being the composition of the principal ones, with the names given to them in the vitrifiable colour trade :—

Rocaille Flux.

Lead oxide	75
Silica	25

(Used for blues and for reds from iron.)

Flux for Carmine.

Red lead	11
Silica	33
Melted borax	55

(Used for carmine and light purple.)

Flux for Violet.

Red lead	67·5
Silica	5·0
Melted borax	27·5

(Used for violet.)

Flux for Turquoise.

Red lead	35
Melted borax	65

(Used for turquoise-blue, sea-green.)

Flux for Greys (1).

Red lead	66
Silica	22
Melted borax	11

Flux for Greys (2).

Red lead	60
Silica	15
Melted borax	25

(Used for greys, yellows, and light browns.)

Flux for Purple.

Red lead	37·5
Silica	12·5
Melted borax	50·0

(Used for purple and the violets made from gold.)

Flux for Green.

Red lead	73
Silica	18
Melted borax	9

or

Red lead	70
Silica	10
Melted borax	20

(Used for chrome-greens, blue-greens, and yellow-greens.)

At the low temperature of muffle firing almost any colouring oxides may be employed. The colour is applied either with a brush or by chromo-lithography (p. 271).

The type of muffle kiln in general use is shown in Fig. 163. For large quantities of ware, a series of muffles side by side are sometimes used, so as to obtain a heating with continuous or semi-continuous firing. Recently, small tunnel kilns have been extensively used, as they are much easier to manipulate and to control. For small quantities, or for heating pieces that need special care, small muffles, as shown in Fig. 304, are used.

The atmosphere in a muffle should always be decidedly oxidizing.

Refractory or Fireproof Porcelain.

The terms *refractory* or *chemical porcelains* are applied chiefly to articles used for heating substances in the chemical industries, in laboratories, and for domestic purposes—such as basins, retorts, crucibles, tubes, stew-pans, dishes, coffee-pots, etc.

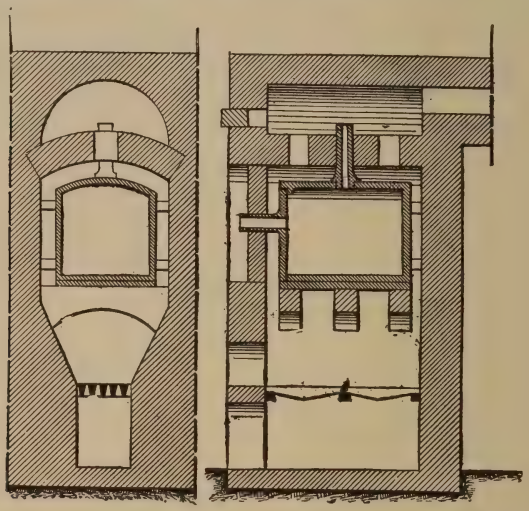


Fig. 304.—Muffle kiln.

The composition of the body differs little from that of the other hard porcelains, but it is often less silicious and more aluminous. For example, the refractory porcelain from Bayeux, which is much valued in France, is composed of—

Silica	61·61 per cent.
Alumina	30·01 „
Oxide of iron	1·56 „
Lime	3·56 „
Potash	3·26 „

This body, when burned, is less translucent than that of tableware porcelain, but it resists sudden changes of temperature better. It should be made of a plastic china clay, or by the addition of a suitable proportion of plastic clay to a leaner one. It is shaped, as has just been described, but the more plastic body lends itself better to moulding. As many of the articles must be thin they are frequently made by *casting* (p. 141).

Porcelain for Electrical Insulators.

The very low electrical conductibility of porcelain makes it valuable for making insulators for electrical purposes (Fig. 305).

The bodies employed should be rather plastic, so as to be readily moulded into complicated shapes, the translucency being of minor importance. They are usually cast in a mould and are re-pressed,

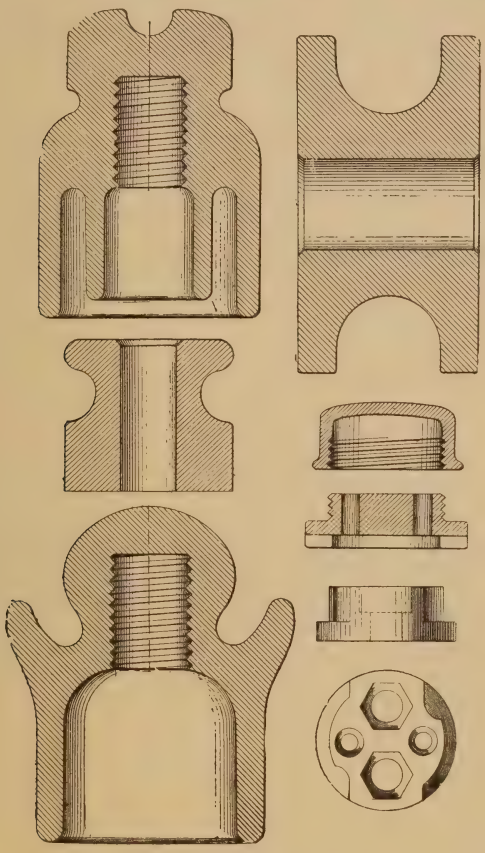


Fig. 305.—Electrical insulators.

when stiffer, in lever presses. The filleted parts are sometimes finished on the lathe, as for some purposes it is necessary for them to be exact, so that they may fit other articles.

Porcelain for Mechanical Purposes.

The hardness of porcelain and its resistance to cracking permit it, in some cases, to be employed for mechanical purposes, principally for grinding, as porcelain mortars, and for lining ball mills and Alsing cylinders. As it is necessary to have a very hard article of accurate shape, this kind of porcelain is made in the same manner as those used for electrical insulators. After being moulded, the stiffened

body is re-pressed in hydraulic presses. The burned ware is turned to shape very exactly by means of emery, black diamond, or with a fine carborundum wheel, these being the only materials available whose hardness is greater than that of porcelain.

There are many other cases in which the remarkable qualities of hard porcelain could be used with advantage in machinery.

Architectural Porcelain.

The Chinese used porcelain in architectural decoration and even in the construction of walls as far back as 954 A.D., though this material is not suitable for making thick articles in consequence of its great shrinkage and its cost.

For architectural decoration, porcelain has no advantage over stoneware, while its high price and the difficulty of making it are serious drawbacks. Extreme hardness and translucency, which make hard porcelain the most perfect material for table-ware, lose their importance in monumental pottery.

Matte Porcelain (*Biscuit Porcelain*).

The body of hard porcelain may, naturally, be used without a glaze. It is then called *biscuit porcelain*, though this term is unsatisfactory.

The most plastic porcelain body, called *sculpture body* or *parian*,[1] is used. It has a composition similar to that used at Sèvres.

Seger recommends a body formed of 54 parts of Zettlitz kaolin, 45 parts of Norwegian felspar, and 1 of marble, mixing 30 parts of the burned mass (grog) to 70 parts of the raw body. The ware should be burned at about Seger cone 9.

The moulding, saggaring, and burning of these matte porcelains are done in the same manner as other hard porcelains. After burning, the body must remain dull and must not commence to vitrify, or it would have a disagreeable, greasy appearance later.

Soft or Tender Porcelain.

The *soft* or *tender porcelains* were originally devised to imitate Chinese porcelain, but as those engaged in this work had not sufficient knowledge, the imitations differed very greatly from the original. Most of these soft porcelains contain more "glassy" matter than hard porcelain, and in some a frit is one of the chief constituents.

The soft porcelains are much more fusible than hard porcelain, and lack some of the beauty of the latter.

The chief varieties of soft porcelain are *bone china*, *vitreous porcelain*, including *new Sèvres porcelain*, *Seger's porcelain*, *parian ware*, and *soft felspathic porcelain*. Many others have been made in small quantities, but are of no industrial importance.

[1] For true parian ware see p. 460.

Bone China, or English Porcelain.

The only soft porcelain of great industrial importance is phosphatic porcelain or bone china, which is manufactured almost exclusively in England. It requires a much lower temperature for burning than hard porcelain, and consequently is less costly and easier to decorate. The body is moderately translucent and milky white. Its chief disadvantage is its lack of hardness and its low durability, and to continental potters it is very curious that English people prefer this porcelain when hard porcelain could be so easily manufactured. Such a criticism overlooks the special advantages which bone china offers to the potter by the greater plasticity of the body, the lower firing temperature, and the much greater range of colours available for decorating it. Nor is the claim that it is more easily scratched and is less durable than hard porcelain a very substantial one—at any rate, for domestic purposes—though it may be somewhat more applicable to ware used in restaurants and hotels.

Bone china differs from hard porcelain in the body being fired at the full burning temperature, the glaze being finished at about 100° lower, whereas hard porcelain is first fired at a low temperature and the glaze is finished at a much higher one. Consequently many under-glaze colours can be used on bone china which would be spoiled if heated to the temperature required to mature the glaze on hard porcelain. The special characteristic of this porcelain is the large proportion of calcined bones or *bone ash* (see p. 43), which are composed chiefly of calcium phosphate, a little calcium carbonate and some magnesia.

The body varies somewhat in composition. The following figures were collected by Prosser :—

China clay	30	28	23	—	23	30
Cornish stone	18	30	31	23	27	7
Plastic clay	—	—	—	23	—	4
Quartz	—	—	—	14	—	3
Biscuit (grog)	5	—	—	—	—	—
Calcined bones	47	41	46	40	46	50
Alkaline frit	—	—	—	—	3	6

This frit is composed of :—

Cornish stone	56 to 60
Quartz	20 „ 30
Soda	8 „ —
Borax	8 „ 10
Zinc oxide	8 „ —

According to W. Burton, the average English bone china is made from 4 parts of bone ash, $3\frac{1}{2}$ parts of china clay, and 4 parts of Cornish or china stone ; the glaze having a basis of felspar and china clay rendered more fusible by the addition of borax, lime, and lead oxide. The limits of composition are, however, exceedingly wide, and depend greatly on the materials used.

Plastic clay is occasionally added to the body to increase its plasticity ; it makes the goods easier to mould, but at the expense

of translucency and whiteness, so that it is only used for making ware of inferior quality.

The composition of the glaze is very similar to that for felspathic earthenware—viz., alkali-boracic plumbiferous—the following being typical :—

Frit.				*Glaze.*			
China clay	34	—	12	Frit	70	60	65
Cornish stone	—	38	20	Cornish stone	9	20	11
Quartz	14	24	15	Quartz	—	—	11
Chalk or marble	18	11	18	White lead	21	20	13
Borax	34	27	35				

The body is made up from liquid slips, though in a few factories the raw materials are measured in a powder and not in slip. The body, being only slightly plastic, presents the same difficulties in moulding as that for hard porcelain. The most usual methods are casting and jolleying, and more rarely, pressing by hand in plaster moulds.

The first or biscuit firing is in the round up-draught kilns (Figs. 147 and 148), the pieces being placed in saggars. For the best qualities, i.e. those richest in phosphate and alkalies, it is necessary to dust portions of the surfaces with finely ground flint or quartz to prevent them from sticking. The ware is burned at the same temperature as that used for felspathic earthenware (according to W. Burton, 1250° C.), and the two wares are sometimes burned simultaneously.

As the biscuit is not very porous, the glaze must be rather thick ; it is applied by dipping. The thickness of the layer of glaze is less than for hard porcelain.

The arrangement of the glazed ware in the saggars (Fig. 273) is much easier than is the case with hard porcelain, as bone china is more plastic and the articles are less liable to lose their shape. Moreover, the finishing temperature of the glaze being lower than for hard porcelain the risk of loss of shape from overheating is much less.

The glazed or *glost* ware is fired at a temperature rather lower than that used for hard porcelain, being usually only 1050° to 1150° C., so that a wider range of under-glaze colours is possible.

The colouring may be applied under-glaze as with felspathic earthenware, or over-glaze as with hard porcelain. Lithographic printing over glaze is also frequently employed, the decoration being touched up with vitrifiable colours put on with a brush. The backgrounds may be made by covering the glaze with a lithographic varnish and dusting on some vitrifiable colour. The methods of decoration available are more numerous than for hard porcelain, and the muffle colours are more brilliant, because the glaze, which is more fusible, agrees better with the vitrifiable colours.

In England, the manufacture of bone china, fine earthenware, and fine stoneware is concentrated in the district known as " the Potteries " in Staffordshire.

Soft Vitreous Porcelain (French Porcelain).

This porcelain, sometimes termed *fritted porcelain* or *Reaumur porcelain*, was the first porcelain to be made in France. Its manufacture was abandoned shortly after the discovery of hard porcelain, but from time to time new attempts at making it are taken up, though they are generally of short duration.

Soft vitreous porcelain is not really a ceramic product, though its use, appearance, and the processes of its manufacture caused it to be classed among pottery. It is really a glass, heated to a temperature which is not sufficient to melt it but enough to give it a milky transparency, the glass forming the body being covered with a softer glass.

The body was composed in the following manner :—

Frit.		*Body.*	
Fontainebleau sand	60·0	Frit	75
Saltpetre	22·0	White chalk	17
Grey sea salt	7·2	Calcareous Argenteuil marl	8
Rock alum	3·6		
Alicante soda	3·6		
Montmarte gypsum	3·6		

The frit was broken into small pieces and carefully sorted, only the fully vitrified parts of the frit being used ; these were ground and added to the chalk and marl, then ground again in water, in such a way as to reduce the grains to an impalpable state. The product was dried, and made into a paste by the addition of water, green soft soap, and parchment size. Its composition is almost exactly the same as that of some plate-glass.

On account of the almost entire absence of plasticity, the moulding could only be done by putting a thick layer of body into a plaster mould which had the outside form of the object, and compressing it with a plunger, also of plaster, which roughly represented the form of the inside space, only smaller. The dried piece was finished by turning.

The placing in saggars was very difficult on account of the softening and great shrinkage of the body, and articles had to be held up with supports made of raw body, which would shrink the same as the ware. The burning consisted, as in the case of faience, of a first heating to vitrify the body, and a second burning at a lower temperature to fix the glaze.

The glaze was composed of :—

Litharge	38
Fontainebleau sand	27
Calcined flint	11
Potash	15
Soda	9

These materials were mixed, melted, ground, made into a slip, and applied to the ware by pouring.

In the second, or glost, burning, the pieces were simply stood on their bases, either in glazed saggars or in muffles.

The colours, with the addition of a small proportion of alkaline fluxes, were over-glaze, rather brilliant, and harmonized remarkably well with the glaze.

The losses in manufacture due to twisted and misshapen ware were so great that the manufacturer could never compete with that of hard porcelain or bone china.

Soft Vitreous Porcelain (*New Sèvres Porcelain*).

In 1884, the pottery at Sèvres, after many attempts to find a porcelain which would lend itself better to decoration than does hard porcelain, and especially one which would produce a turquoise blue from copper, brought out what was then a new kind of ware, to which the name of *New Sèvres Porcelain* was given. According to Lauth and Dutailly, the body is composed of—

Frit.		*Body.*	
Sand	77	Fontainebleau sand	49·02
Soda	8·5	Frit	27·45
Saltpetre	16·5	Chalk	16·66
Chalk	18·4	Plastic clay from Dreux	6·86

This composition is similar to that of the preceding porcelain, from which it differs only in having a larger ratio of lime to alkalies, and a slightly greater amount of alumina and silica as compared with the fluxes.

The body, although slightly more plastic than that of French porcelain, is still very weak, and the moulding presents difficulties which are more easily overcome when objects of luxury are manufactured than when commercial products are to be produced.

The first burning (at Seger cone 9) is intended to vitrify the body, and not, as in hard porcelain, to convert it into biscuit. The saggaring is the same as for glazed, hard porcelain.

Either of two kinds of glaze were used, composed of :—

	A	B
Sand	25·52	35·15
Chalk	8·60	7·43
Pegmatite	65·98	—
Felspar	—	57·42

Both these correspond to RO, 0·64 Al_2O_3, 6·77 SiO_2, which clearly distinguishes the new porcelain from the French soft porcelain, the glaze of which is an alkaline plumbiferous one.

The glaze is applied either by dusting or by dipping.

The decoration, which is the essential feature of this class of ware, may be under-glaze, stained glaze, or over-glaze. The temperature of the glost firing is sufficiently low to allow the production of the blue from copper and of reds from iron.

Argillaceous Soft Porcelain (Seger's Porcelain).

This porcelain has been manufactured since 1886 in the factory in Berlin. It originated in an attempt by Seger to reproduce the ancient Chinese porcelain, just as Reaumur and others at the Sèvres pottery, but the different starting-points led to very different results. The people at Sèvres started with French soft porcelain, but Seger took as his pattern Japanese porcelain. The following are the different compositions of the body at which he stopped :—

Plastic clay	31·0	15·5	15·5
Zettlitz kaolin	—	—	13·0
Sennewitz kaolin	—	19·0	—
Felspar	30·0	30·0	30·0
Powdered Hohenbocke sand	39·0	35·5	41·5

Seger found from rational analysis that the clays and kaolins he used were equivalent to the following mixtures of " pure clay " and sand :—

	Pure clay.	Sand.
Plastic clay	81	19
Zettlitz kaolin	97	3
Sennewitz kaolin	65	35

The chemical composition of Seger's porcelain is approximately as follows :—

Silica	77·0 to 75·5
Alumina	17·0 „ 17·5
Lime	0·30
Magnesia	0·20
Potash	3·75 „ 3·80
Soda	0·65 „ 0·70

which can be represented by the formula $0{\cdot}38RO$, R_2O_3, $7{\cdot}7SiO_2$, and is almost identical, as to rational analysis, with the composition of Japanese porcelain.

The glaze is similar to that of the Japanese glazes, viz. :—

Sand	27·3	21·0
Zettlitz kaolin	13·0	—
Sennewitz kaolin	—	19·2
Felspar	42·1	42·1
Marble	17·7	17·7

and corresponds to the formula—

$$\left.\begin{matrix}0{\cdot}7CaO\\0{\cdot}3K_2O\end{matrix}\right\}0{\cdot}5Al_2O_3,\ 4SiO_2.$$

Seger thus completely imitated the Japanese porcelains from a chemical point of view, but in physical properties Seger's porcelain is less translucent, less hard, more fragile, and of a slightly yellowish tint. The body is plastic enough to lend itself easily to moulding ; the articles are then, like hard porcelain, heated to convert the ware into biscuit, then glazed and burned at a temperature sufficient to

bend Seger cone 9. This comparatively low temperature for burning (the same as the new Sèvres porcelain) and its slight hardness, has caused this ware to be placed among the soft porcelains.

Matte Soft Porcelain (*Parian Porcelain*).

The various kinds of soft porcelain may, like the hard porcelains, be hard-fired without any glaze. Up to the present time, only French porcelain has been used for this purpose, and this gives dull ware of beautiful appearance. Dull, phosphated porcelain or bone china is less satisfactory, and has been replaced by a special body, which, when burned, has a slightly yellowish colour, with a dull yet smooth surface, reminding one of the beautiful marble from Paros, whence its name of *Parian ware.*

Parian body is chiefly composed of a mixture of china clay and felspar ; the latter, under the influence of the high temperature, becomes semi-fused, giving the ware a milky appearance. According to Prosser, its composition is :—

Frit.			*Body.*			
Kaolin	11	—	Frit	15	9	—	—
Felspar	25	—	China clay	39	28	33	37
White sand	58	83	Felspar	39	42	44	63
Potash	6	18	Cornish stone	—	22	14	—
			Flint glass	6	7	—	—

According to W. Burton, however, Parian ware was apparently invented by Copeland and Garret of Stoke-on-Trent, about 1845, and English " Parian " is composed of 1 part of china clay to 2 parts of felspar. It is fired at 1150° C. to 1200° C., and is sometimes glazed with the ordinary lead glazes used for English china ware.

The body may be coloured so as to produce imitations of ivory or different natural stones, whence the names of " malachite," " lazulite," " porphyry," and " obsidian " wares.

The plasticity being so slight makes the moulding rather troublesome, so the ware is usually shaped by casting. It is fired at the same temperature as phosphated porcelain (bone china), but the shrinkage, as well as the softening of the mass, necessitate very careful placing in the saggars, the projecting parts being held up by supports made of raw body.

Matte, Felspathic, Soft Porcelain.

Small objects, buttons, and imitations of pearl and agate are made of a matte felspathic porcelain. This manufacture was invented about 1840 by Prosser, who first used the English porcelain or bone china body, then simply a mixture of felspar and bone ash, to which plasticity was given by the addition of oil, which was destroyed when the ware was burned.

Bapterosse introduced this industry into France and, by the use

of special processes and very perfect machinery, entirely "killed" the English trade.

The body is formed of felspar, which is powdered and treated with sulphuric acid to separate part of the impurities (iron oxide). To the purified felspar is added some colouring oxides, or sometimes a little bone ash or chalk. Milk or an emulsion of caseine in a solution of boracic acid is next added, so as to give the material a consistency firm enough for it to be moulded in a press. Five hundred buttons are moulded with one stroke. They are arranged automatically on a sheet of paper, which is used to carry them on to a fireproof plate. This is first heated, so that the paper is burnt up; then the plate is put into a muffle, where it remains for about ten minutes. It is then drawn out, the buttons on it are taken off with one stroke of a rake, and it is covered with a fresh sheet of paper. As many as thirty muffles are sometimes arranged in a rectangular down-draught kiln. The burned buttons fall into a series of boxes fastened to a pivot, where they finish cooling, and from which they are taken out through a movable bottom. They may be then decorated, if required, by chromo-lithography with vitrifiable colours, or gilded. Cameos and small cubes (mosaics), and, more recently, many small electrical fittings, both of porcelain and fine stoneware, have also been manufactured by this process.

THE END.

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